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PB-284 013

Effects of the Disposal of Coal Waste and Ashes in Open Pits

Central Research and Design Inst for Open-Pit Mining,
Wroclaw (Poland)

Prepared for

Industrial Environmental Research Lab, Cincinnati, Ohio

Apr 78

United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Cincinnati OH 45268

EPA-600/7-78-067
April 1978

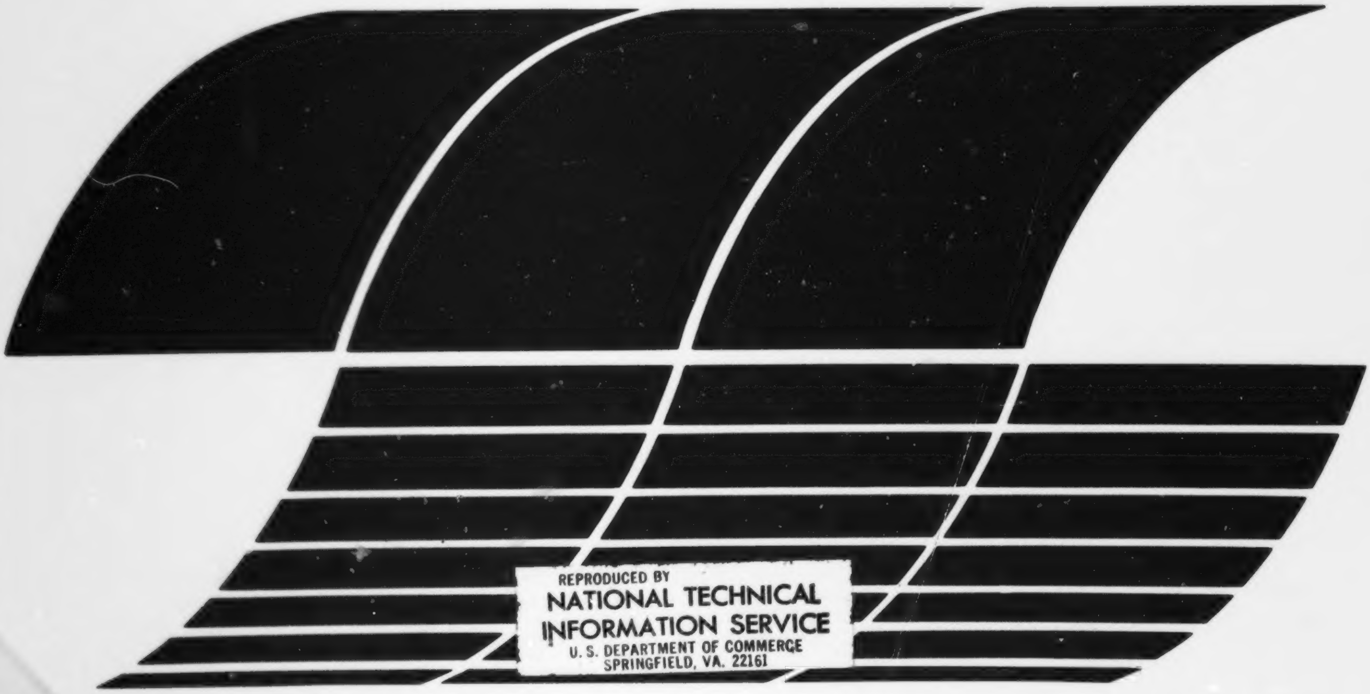
Research and Development

EPA

PB 284 013

Effects of the Disposal of Coal Waste and Ashes in Open Pits

Interagency Energy-Environment Research and Development Program Report



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April 1978

EFFECTS OF THE DISPOSAL OF COAL WASTE AND ASHES IN OPEN PITS

by

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Project No. 02-532-10

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FOREWORD

When energy resources are extracted, processed, converted and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The U. S. Environmental Protection Agency through its Regional Offices and Office of Research and Development is striving to develop and demonstrate new and improved methodologies that will meet these needs both efficiently and economically.

The effort reported here was conducted as part of the Environmental Protection Agency's Scientific Activities Overseas Program and was a cooperative venture between Region III and the Industrial Environmental Research Laboratory-Cincinnati. The research was conducted by Poltegor, the Main Research and Design Center for Opencast Mining, Wrocław, Poland.

In this report the impact on groundwater when coal refuse and power plant ash are disposed of into inactive mine pits is ascertained. Based upon these findings, recommendations for the disposal of these wastes into pits are made for various hydrologic and geologic conditions.

Results of this work will be of interest to persons concerned with groundwater pollution and in the design of coal refuse and power plant ash disposal systems. Furthermore, it should be of interest to those persons developing regulations for and enforcing the Clean Water,Resource Conservation and Recovery and the Drinking Water Acts.

For further information contact Project Officer, Region III or the Resource Extraction and Handling Division, IERL-Cincinnati.

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SCIENTIFIC ACTIVITIES OVERSEAS

(Special Foreign Currency Program)

Scientific Activities Overseas, developed and implemented under the Special Foreign Currency Program, are funded from excess currencies accruing to the United States under various U. S. programs. All of the overseas activities are designed to assist in the implementation of the broad spectrum of EPA programs and to relate to the world-wide concern for environmental problems. These problems are not limited by national boundaries, nor is their impact altered by ideological and regional differences. The results of overseas activities contribute directly to the fund of environmental knowledge of the U. S., of the host countries and of the world community. Scientific activities carried out under the Program therefore offer unique opportunities for cooperation between the U. S. and the excess foreign currency countries. Further, the Program enables EPA to develop productive relationships between U. S. environmental scientist and their counterparts abroad, merging scientific capabilities and resources of various nations in concerted efforts toward U. S. objectives as well as their own.

Scientific Activities Overseas not only supplement and complement the domestic mission of EPA, but also serve to carry out the mandate of Section 102(2(F)) of the National Environmental Policy Act to "recognize the world-wide and long-range character of environmental problems, and where consistent with the foreign policy of the United States, lend appropriate support to initiatives, resolutions, and programs designed to maximize international cooperation in anticipating and preventing a decline in the quality of mankind's world environment".

This study has been funded from Pulbic Law 480. Excess foreign currency money is available to the United States in local currency in a number of countries, including Poland, as a result of a trade for U. S. commodities. Poland has been known for its extensive mining interests, environmental concern, and its trained and experienced engineers and scientists in this important energy area.

ABSTRACT

The objective of this study was to determine the extent of groundwater quality deterioration when coal mine solid waste (refuse) and power plant ashes were disposed of into open pits. In addition, disposal methods were developed and procedures for planning and designing disposal sites were formulated. Pilot studies were conducted at two experimental disposal sites, at which the groundwater was monitored. As backup to these tests, laboratory studies of the physical-chemical properties of the waste, and its leachate were conducted. Based upon the results of these studies, a full scale demonstration was conducted. From this work, the physical-chemical character of the waste material and its susceptibility to leaching of particular ions in a water environment were determined, as was the influence of precipitation on the migration of pollutants (TDS, Cl, SO_4, Na, K, Ca, Mg, NH_4, PO_4, CN, phenols, Cd, Sr, Cu, Mo, and B) to the aquifer. The level of pollution of groundwater in the vicinity of disposal sites and its dependence on local hydrogeological conditions, and particularly on hydraulic gradients was ascertained.

Recommendations for improved waste storage technology in order to limit the effect on groundwater to a minimum and guidelines for designing a monitoring system are presented.

This report was submitted in fulfillment of project number PR 02-532-10 between the United States Environmental Protection Agency and the Central Research and Design Institute for Openpit Mining, POLTEGOR, 51-616 Wrocław, Rosenbergów 25, Poland.

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ACKNOWLEDGEMENTS

This report was prepared on the basis of research project completed by the Central Research and Design Institute for Openpit Mining POLTEGOR, in Wrocław, Poland. In this project support was also given with the assistance of specialized observation stations and laboratories of the Meteorology and Water Management Institute. The scientific concultations were provided by dr. Kleczkowski - professor of Mining Academy in Kraków.

The entire research work was directed, and the report prepared by the Principal Investigator Mr Jacek Libicki, M.Sc. Geologist.

On the part of the Environmental Protection Agency of U.S.A. the supervision on the research project was performed by Project Officers Mr. Edgar A. Pash of the Office of Water Program Operations, Washington D.C., and Mr. Stephan Wassersug, Director of the Enforcement Division, EPA Region III. Both the Project Officers helped and adviced Poltegor in the course of the project performance, and provided us with contacts of appropriate Institutions in the U.S.A. helping us learn American experiences in the execution of similar investigations. In this way we could better understand the needs and requirements of the ground water environment protection in the U.S.A.

The organizational and financial help was given by Mr. Thomas J. Lepine, the Chief of the Special Foreign Currency Program of EPA, the funds of which supported the project expenses.

The specialists from other institutions in the U.S.A., especially from the United States Geological Survey, Denver Research Institute, from Desert Research Institute in Las Vegas and from the US Bureau of Mines and State of Pennsylvania authorities consulted the project problems´ issue, and acquainted us with their research effort on similiar fields.

We kindly appreciate all Institutions and Persons for their help and advice.

SECTION 1

INTRODUCTION

A fast rate of industrial development in the world causes the creation of large industrial - municipal agglomerations producing large quantities of sewage, garbage and waste material of all sorts. Amongst others in the regions where the coal mining is developed, large amounts of waste materials are produced by the mines and by power plants fired with coal. Sometimes a high density of people on these terrains, and the shortage of land create situations, where it is difficult to find suitable sites for the disposal of these wastes. In search of such places, old abandoned open pits are often chosen for this purpose.

However, this seemingly rational solution conceals in itself a very serious danger; the possibility of ground waters pollution with substances leached from the disposed waste material. These substances filtrating to the environment of ground waters may migrate for long distances polluting large volumes of waters within the aquifers exploited for drinking and for commercial purposes.

This brief description of phenomena occurring in the course of waste storage in abandoned open pits demostrates the main problems, to be considered, and if possible solved to enable the forecast of eventual effects of wastes storage, and to undertake optimum decisions in this field.

The first group of problems is the physico-chemical characteristics of waste material considered particularly in the aspect of its susceptibility to dissolution in aqueous environment of some components of the wastes, and their convection out of the disposal in a form of solutions. Some components may be washed in a mechanical way and carried as suspended matter, but this phenomenon has a much more limited range and the quantity of these pollutants is quickly reduced during filtration through a porous medium.

The second group of problems is the influence of hydrogeological factors on the possibility of infiltration of pollutants to the ground waters. To these factors belong in the first place the spacial interrelation of the waste disposal and the ground water table, and the hydraulic characteristic of layers separating the disposal from the aquifer. Following possibilities could be distinguished here:

- disposal separated from aquifer by impermeable layer
- disposal separated from aquifer by permeable but unsaturated layer
- disposal immersed in the aquifer.

The third group of problems is the influence of hydrogeological factors on the possibility of pollutant migration within the aquifers. These factors will be:

- the permeability of the aquifer
- hydraulic gradient (head of water table)
- time
- heterogeneity of geological structure (foldings, intercalations etc.).

The fourth group of problems are processes of a physical and chemical nature occurring in the course of pollutants′ migration through the soils, and especially:

- natural dilution of polluted liquid in the mass of pure ground water
- dispersion and diffusion
- absorption
- ion exchange between liquid and soils
- other chemical reactions.

The fifth group of problems are issues of pollutants′durability - this is a problem very complicated and not easily solved. The durability of pollutants should be considered in respect to:

- the type of polluting factor
- velocity of waters exchange in the aquifer, which is the balance of waters delivered and offtaken
- spatial relation among the pollutants´ sources, regions of feeding and regions of drainage of the aquifer.

The sixth group of problems are issues connected with the methods of artificial prevention of contacts from the mixing of polluted waters with pure ground waters. Selection of adequate solutions and methods of action should be based on technological possibilities and economic expediency.

As can be seen from this analysis of formation and of distribution of pollutants the storage of waste material from coal mines and from power plants in old open-pits is an extremely complicated issue. It is a result of many and very different factors, the number of possible variants being practically unlimited.

In approaching the study of the project one should imagine the entire complexity of the problem, and select the most critical elements.

Therefore, the provision of universal solutions is not possible. Nonetheless it is possible to evaluate the course of phenomena and to provide certain general and fundamental relationships, and a methodology of planning and designing for such disposal in the decision making.

The 59 tables containing the groundwater chemical analyses were excluded from this edition of the report. These tables are available to interested parties in the Office of the Principal Investigator and Project Officer.

SECTION 2

CONCLUSIONS

Detailed conclusions concerning particular problems are presented at the end of each section and in this place are presented in a general form.

1. Disposal of gob and of coal fired power plants, ashes localized in old open pit, which may have a direct or indirect contact with ground waters, exerts a substantial influence on the deterioration of their quality, althought does not produce conditions of direct poison.

2. This influence is a function of very many factors, and the final effect is a result of very many phenomena making up the whole process.

3. The waste material under study does not constitute a homogeneous material with a uniform characteristic and one could separate out from it the following:

   - "dry" mining wastes (gob)
   - "wet" mining wastes (from water washers, from washers using heavy fluids, and from flotation)
   - slags (bottom ashes)
   - fly ashes.

   Each type of these wastes creates different hazards in different conditions for the ground water´ quality.

4. For an adequate planning of the waste material storage it is necessary to have a knowledge of a physico - chemical character

of the wastes determined for specific disposal and specific hydrogeological conditions of storage.

5. For the determination of hydrogeological conditions of storage the most essential thing is the reconstraction of a hydrodynamic heads network, whereby for disposals being non - point sources of pollution the most appropriate at the present time appears to be methods of classic hydrogeology.

6. An experimental disposal of gob from coal mines (70 %) and of fly ashes (30 %) situated directly in the roof of aquifer layer causes a distinct pollution of ground waters in the following quantitative relations.

TDS	increase to 10 times
Cl	increase to 40 times
SO_4	increase to 10 times
Na	increase to 100 times
K	increase to 20 times
Ca	increase to 6 times
Mg	increase to 2 times
NH_4	increase to 4 times
PO_4	increase to 8 times
CN	increase to 10 times
phenols	increase to 2 times
Cd	increase to 3 times
Sr	increase to 5 times
Cu	increase to 6 times
Mo	increase to 15 times
B	increase to 25 times.

It does not exert influence clearly on the change of the pH reaction nor a clear increase in the Fe, Mn, Al, Cr ions content, although these were present in the waste material. A small increase was noted in the case of the Zn, Pb and Hg ions.

During $2^1/2$ years from the disposal of 1500 m^3 capacity 11.5 tons of pollutants were diluted (0.78 % of its total mass) which means about 70 % of total dissoluble components.

7. Each ion has a different susceptibility to leaching and to migrating in the ground waters environment.

8. In the initial phase of the investigated disposal the increase in the pollution concentration was dependent visibly on the amounts of precipitation, and later-on these waves of pollutions were gradually superimposing themselves upon one another, and smoothing out so that the pollution had a continuous character.

9. The main body of pollution is convected in conformity with the main stream of ground waters and the lateral dispersion, as it does not exceed a few meters. This last phenomenon in the case of large size disposal does not appear to be the main element of the whole phenomenon estimation. But one has to take into account the fact, that every ion behaves differently.

10. Durability of the pollution by the rain-leached pollutants contained in a disposal 2.5 m thick is different for different components. In the case of e.g. Cl ion this amounts to about 3 years; and for some heavy metals it may exceed 10 years.

11. For an objective estimate of a part played by disposal in the formation of the ground waters quality it is necessary to have always comparison samples, as ground waters undergo very many influences.

12. Longer than 1 month time intervals between the sample takings during the main period of observations create difficulties in the interpretation of results.

13. The model tests enabled a cross - sectional demonstration of the pollutants' propagation and the effects of some selected factors on the shape of the polluted stream and also the working out of prognosis for the large disposal no. 2.

14. The possibilities exist for proper wastes storage so that their influence exerted on ground waters could be limited to a minimum, and there exists also technical means of artificial insulation, which can be utilized.

SECTION 3

RECOMMENDATIONS

In connection with this as described in next sections, the disposals of the coal mines refuse and coal fired power plants ashes stored in old, abandoned open pits may effect a real deterioration in the quality of ground waters (causing however no risk of direct poisoning). And the following proposed recommendations of procedure are presented.

WASTES CLASSIFICATION AND TESTING

1. The investigations clearly suggest the necessity of an effective division of the waste material coming from the coal mines and from coal fired power plants into sub-groups. These sub-groups should be based upon mechanical and chemical characteristic of leaching toxic compounds from the refuse in a water environment.

2. Coal mine refuse should be divided into dry and wet waste.

   (i) The dry waste material is coming from so called quarry operations, associated with the ripping of floor or roof, the construction of stone drifts etc., and more rarely from dry separation (mechanical). These wastes are characterized with identical mineral and chemical composition, to the sterile rocks accompanying the coal seams, and are usually quite coarsely grained (gross from 10 to 200 mm). In connection with this the pollutants leached from it are in its qualitative aspect entirely dependent upon the chemical composition of sterile rock formations. The quantity of these pollutants which may pass into solution is relatively small, because of the small surface contact with the washing water (the effect of large granulation of this refuse) and to great filtration velocity of water through this type of gob; this is taking place particularly with cases of"dry disposals," i.e. located above the ground water table.

(ii) Wet waste material may be coming from washers using water or heavier fluids, and from flotation processes

- the wastes from the water washers are characterized with a granulation from a silty fraction up to ϕ 80 mm fraction, and their chemical composition is a function of both the sterile rock and the cleaned coal. Moreover the influence on their chemical character is dependent upon the composition of used wash water (this can be e.g. a highly mineralized drainage water). The wide range of the granulation provides conditions for both the movement of the water through the stored material, and a large contact surface with refuse for leaching greater quantities of components than with dry refuse. Moreover independent of pollutants of a chemical type, pollutants from the washed out material may also be convected in a shape of finest grained silty fractions (suspension)

- waste materials coming from washers using heavy fluids are characterized by a coarser graining than waste from water washers, (mainly being within limits of 20 - 250 mm); their chemical composition is similar to the composition of the accompanying the seam sterile rocks. The chemical composition of the heavy fluids used has also a substantial influence; particularly during the course of washing, the components of washing medium settle on the surfaces of granules, and in first succession are washed out from the disposal. The chemical character of this fluid should be a subject of interest from the environmental point of view. The quite coarse granulation of such refuse does not provide conditions for the leaching of large quantities of components from them because of the relatively small contact surface of the refuse grains with the filtrating water, and the considerable, velocity of the rain water filtration, (specially in case of dry disposals)

- the flotation waste material is characterized with a very fine granulation in fractions from silty to 2 mm diameter. Their chemical composition is a function of the coal character, its accompanying sterile formations, and also of the chemical substances used as flotation fluids. The fine granulation of these wastes provides conditions for leaching from them in a water environment large quantities of components particularly in wet disposals saturated with water. In case of dry disposals a fine granulation of this refuse limits the possibility of the filtration of the rain water through the stored material and may increase the evaporation in the disposal's water balance. The composition of the fluid used in the flotation process may also be of substantial influence on the chemical character of leachatesm Some of the fluid's components may settle on the surface of grains. The type of fluids used in flotation should therefore also be controlled in this aspect of refuse storage.

3. Waste materials from power plants fired with coal, should be divided into fly ashes and slags.

   (i) The ashes are characterized by a very fine granulation composition and a chemical composition subject to the quality of coal burnt in the power plants. The quantity of pollutants which can be leached from ashes and passed into ground water is theoretically very great, because conditions for leaching are provided by very fine graining, giving a large contact area with water (by full saturation). Practically this quantity is much smaller due to the lesser permeability of ashes, especially when disposals are situated above the ground water table. The character of these pollutants depends on the chemical character of the burnt coal.

(ii) The slags are characterized with a similar chemical composition to the ashes, but of a much coarser graining. The quantity of pollutants which can be leached from slags and pass into the ground water, although theoretically smaller than in case of ashes (smaller contact area of particular granules with the leaching water) because of their good permeability, can in practice, be approximated. This is applicable to deposits situated above the ground water table and to deposits situated below as well. The character of the pollutants depends on the type of burnt coal.

4. The threat to ground waters as posed by particular types of waste, assuming their comparative chemical compositions under various conditions of the storage, from the most harmful as follows:

in conditions of precipitational leaching	in conditions of full water saturation
1. wastes from water washer	1. wastes from water washer
2. wastes from heavy washer	2. ash
3. slags	3. flotation wastes
4. wastes of dry separation	4. wastes from heavy washer
5. fly ash	5. wastes from dry separation
6. flotation wastes	6. slags.

5. Laboratory tests of wastes with respect to their storage should be carried out considering the conditions of storage, and the available time.

6. In connection with the statement in pt 5, it would serve no purpose to perform a full chemical analyses of wastes as this can lead to erroneous conclusions, because only portion of their com-

ponents can pass into free solution, and only this portion is affecting the quality of ground waters.

7. When there is enough time and available funds for the tests performance, the most adequate method is the lysimetric tests carried out in columns of a 1 m diameters rank, and 3-4 m high. Such tests are very long (6 months to 1 year). The proportions of water and the wastes, should be considered at saturation when the material is intended for storage below the ground water, to a periodical sprinkling with intensity of a rain when the storage will be subjected only to the filtration of precipitation water. In the first case ground water should be, for leaching, taken from an aguifer within which the storage is planned. In the second case the lysimeter may be installed out of doors, or in laboratory conditions where distilled water could be employed. Such a course of procedure is recommended owing to various dissolving properties of different types of water.

8. For the obtention of faster results an intense leaching of the wastes can be employed in columns of 10 cm diameters and a 1 m height provided with a filtrating layer in the bottom pert. One can obtain then in the course of two weeks approximated results giving information regarding maximal concentrations of particular components which can pass from given waste material to ground water in optimal conditions. In interpretation of these results caution is recommended as in the case of difficult soluble compounds the time is not represented. Such time aspect in the case of ashes can be shortened in increasing the saturation with water to the proportion of 1:1, the result however will be approximated.

9. It is recommended that tests described in pt. 7 be performed, before commencing the storage, and tests quoted in pt. 8 during the course of storage for the check on variabiblity of the being stored material.

10. The physico-chemical analyses of the leachate should take into account all possible concerns to formulate physico-chemical parameters, as one cannot judge beforehand which of these components may show to be harmful.

11. The analyses mentioned in pt. 9 should be performed with the greatest possibly accuracy, as a possible potential threat may pose not only the content of a given toxic component in ground waters, but often also the secondary increased concentration in organisms of plants or animals using these waters. And this secondary concentration may be more harmful.

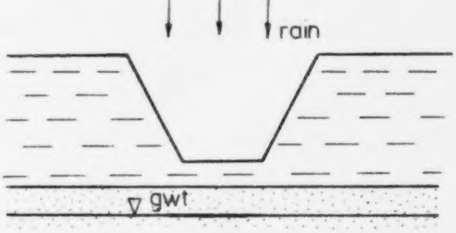
DISPOSAL CLASSIFICATION

Classification and evaluation of the old open pits´ suitability for the storage of discussed waste materials, from the point of view of protection of ground waters, should be made in the aspects of various criteria, the proposals of which are presented below:

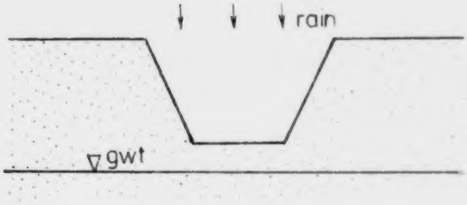
1. The hydrogeological criterion based on reciprocal spatial relations of the disposal and the aquifer, for which it will constitute a potential threat. Proposed here is the introduction of a following classification:

   I. "Dry" disposals type (situated above the ground water table)

   a) localized within reach of impermeable layer

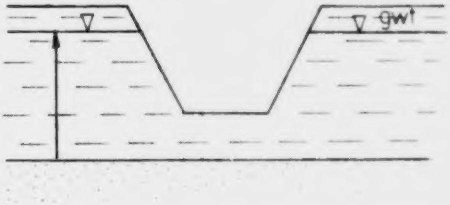


b) localized within reach of permeable layer

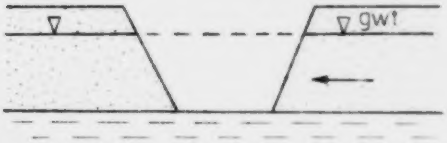


II. "Wet" disposals (situated below the ground water table).

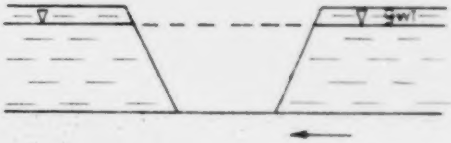
a) localized within reach of impermeable layer underlined with aquifer layer with hydrostatic thrust of ground water table



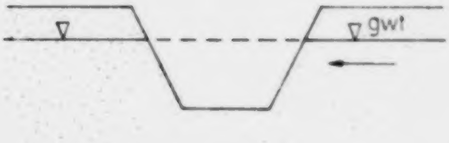
b) localized within reach of permeable layer underlined with impermeable layer



c) localized within reach of impermeable layer directly underlined with permeable layer with hydrostatic thrust of ground water table

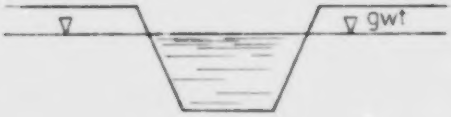


d) localized within the reach of permeable layer



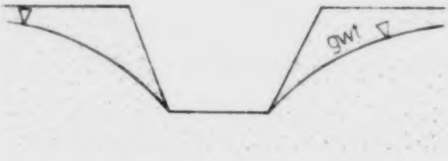
The disposals mentioned in pt II b, c and d could be:

1) filled with water (the waste material stored into water)



or

2) retained in dry state through operating, existing still from the period of excavation draining arrangements (ditches, pumping stations) - the waste material stored in dry open pit and then saturated with water.



In the first of these two cases the pollutants pass into water much faster, and in the second at a much slower rate although the sum of leached out compound in a given optional time length will be approximated.

2. Hydrogeological criterion based on a ratio of the disposal permeability to the surrounding aquifer. It is proposed here to distinguish the:

   A - disposal with the permeability coefficient lower than the surrounding aquifer (should be included here as a rule disposals of fly ashes and of flotation waste materials)

   B - disposals with permeability higher from the surrounding aquifer (included here will be mainly disposals of dry quarry refuse)

   C - disposals with permeability similar to the surrounding aquifer.

3. Criterion of a protected object and proposed here to distinguish are disposals planned in conditions when:

   A - protected must be the entire aquifer

   B - protected must be a determined part of the aquifer, or the determined water intakes.

4. Criterion of interdependent position of the disposal and the protected object and to discern the following contingencies.

   A - protected object is situated in the zone of direct threat posed by waters entering into direct contact with the disposal (downstream of ground water)

   B - protected object is situated in the zone of indirect influence, where pollutants may appear either as very diluted or as a result of dispersion

   C - protected object is situated within the reach of this same aquifer of but outside the hydrodynamic or dispersional influence zone of disposal (upstream of the ground water flow).

5. Criterion of the degree of ground waters protection and proposed here is to distinguish:

   1-st degree, a total protection, when the ground water remain under total protection and their quality cannot be subject to any changes,

   2-nd degree - partial protection - when this is based on prevention to exceed certain permissible values, or on protection of water against increase in content of only determined components (i.e. Cl, SO_4, heavy metals),

   3-rd degree - when a given aquifer is not subject to a special protection.

DISPOSALS PLANNING AND DESIGNING

1. Planning the storage of the coal mining refuse and of coal fired power plants'ashes in an old open pit should be preceded by:

   a - exact knowledge of the gob and ashes character (in the aspect of their eventual influence on ground waters based on tests quoted above and their quantity provided for storage in a given time

   b - accurate recognition of the hydrogeological conditions in which is situated the open pit planned for storage

   c - determinations regarding what part of the aquifer and to what extent the water should be subject to protection.

2. The survey of hydrogeological conditions should comprise:

   - spatial parameters (of thickness, spreading and hydraulic relations with others) of the aquifer entering into contact with the disposal

   - parameters of permeability (especially coefficients of permeability and of specific yield)

   - distribution of a hydrodynamic network of the ground water hydrostatic heads

   - exact knowledge of the original ground waters chemical character

   - lithology of aquifer.

3. Dimensional parameters of investigated aquifer should be surveyed by means of:

   - drilling wells (existing from the period of the deposit exploitation, or specially designed for this purpose)
   - geophysical investigations (where possible)
   - analysis of general geological informations.

4. Parameters of permeability should be determined using standard field tests (e.g. tested pumping, or water forcing in especially in the zone of aeration) or laboratory tests (bleeding in filtration columns, granulometric analyses).

5. Reproduction of the hydrodynamic net should be performed on the base of surveys of the ground water table in bore holes, or where possible by means of remote sensing geophysical methods. The thermistor or tracer methods are not recommended as in case of large size objects and non - point pollutions these are here less adequate than in the case of particular wells. The following model verification of hydrodynamic network is recommended, as there are quite considerable possibilities of its better adaptation to real conditions. This can be obtained using digital or physical modelling methods (e.g. EHDA). The representation of the hydrodynamic net of the disposal region is the most important element of determination of its eventual influence and should be made with the greatest accuracy.

6. The chemistry of water of a considered aquifer should be determined by means of analyses of ground water, sampled several times from the places specified on the basis of the mentioned above investigation, at 2-3 months intervals. This is necessary, due to frequent, e.g. seasonal or caused by other factors, changes in ground water quality (especially in urbanized areas). This phenomenon was observed during presented research.

7. Knowledge of lithology of the aquifer formations is necessary for the evaluation of the phenomena of absorption and ion exchange, that can take place between the pollutants and the rock (soil) skeleton.

8. The assignment of parts of aquifer and the extent to which such parts are to be protected should be made taking into account not only acutal situation, but also future plans of their utilization, because the influence of the disposal may persist even for scores of years.

9. Having data presented above, it is possible to prepare a forecast of influence of the wastes storage in an old open pit on the whole or on a selected part of the aquifer under consideration. Such a prognosis may be of qualitative or quantitative character, both in the aspect of time and the degree of deterioration of the water quality. The forcast may be prepared either with application of computer methods, or a physical analogy or a descriptive computation method. One should realize clearly, that so far there are no all - purpose programs, which would afford a formulation of all phenomena, in a three dimensional system, in the aspect of time considering different behaviour of various ions, and also phenomena occurring in the unsaturated zone. One can make however approximated forecasts enabling proper decisions undertaking. It is possible to obtain more accurate results when the forcast concerns one pollutant only, e.g. chlorides, or molybdenum, and not all the polluting components.

10. Next to forcast the recommendations concerning the method of storage and of eventual prevention means should follow.

11. For particular types of disposals and for various kinds of stored wastes one does see solutions of such storage method, where the influence on ground waters either could be eliminated, or limited, or where could be introduced adequate protection means. And so:

    (i) In open pits of the I-a type the discussed wastes can be stored without any greater limitations.

    (ii) In open pits of the I-b type cannot be stored, without a risk, coarse type wastes (such as slags, gob washed by heavy fluid or from water washers or a dry rock when this contains soluble, polluting components).
    However ashes can be stored or flotation silts with such a shaping surface morphology and such surface reclamation as to increase maximally the superficial run-off of rain water and the evaporation, and to decrease to minimum the leaching of

precipitational water. In case of coarse wastes it is recommended to cover their surface with impermeable material (e.g. clay layer), making impossible infiltration of precipitation into the disposal interior. When mixed wastes is planned to store, it is recommended to place coarse wastes on the bottom and a weakly permeable material on the top. Though the recommendations as proposed for the weakly permeable wastes should be preserved. The above preventive methods may be satisfactory only when the storage is formed as a single horizon and where immediately the shaping of the surface and reclamation in its final profile is possible. It is estimated, that the above methods of operation should diminish the quantity of leaching pollutants to the ground waters by some 80 %. When the open pit has to be filled with wastes successively to several levels, then this method is not applicable and one should employ a temporary surface sealing-off with a plastic sheeting, or total sealing of the bowl of the open pit.

Relevant decisions should also depend on the required degree of the ground water protection and on spatial relations of the disposal to the protected object.

(iii) In the open pit of the II-a type one may store waste material without any greater limitations.

(iv) In open pits of the II-b type the storage of any kind of waste material must lead to a deterioration in quality of the ground waters. This pollution will be smaller, when a smaller amount of waters will flow through the disposal. Therefore it will be smaller the smaller is the disposal permeability to compare with permeability of the surrounding aquifer. In this type of disposals, the pollutants will flow through the whole thickness of the aquifer, therefore in such disposals the discussed wastes can be stored only when the degree of required protection will be of the 2-nd or the 3-rd rank, and when the forcast is showing that the permitted pollution in a given point are not expected to be exceeded. When the 1-st degree of the water protection is required, or when a threat occurs of the permitted pollution level to be exceeded, then it is necessary to employ prevention means, which can be:

- vertical, sealing diaphragm, completed in depth to the impermeable layer made by a digging and filling with impervious material or by grouting method,
- protection of slopes with impermeable plastic sheeting, or sprinkling with substances, which when coagulated set an impermeable layer (this bonding is possible only then when the disposal bowl in the course of storage is not filled with water),
- barrier of wells pumping water back to within the reach of the disposal.

The selection of means should be based on economic criteria.

(v) In the open pits of the II-c type one can store all kinds of discussed wastes when thedegree ofthe water protection is of the 2-nd or 3-rd degree. Due to the balanced hydrostatic head and no factor from the pure and polluted waters density difference, there will be no large scale migration of pollutants in vertical. Such migration will take place only on a rather small scale and only in the effect dispersion. Within the aquifer these pollutants will occur exclusively in its uppermost part. Should a total disposal insulation from ground waters be considered, then the most appropriate solution could be a clay sealing of the disposal bottom, through spreading on the water surface of corresponding quantities of clay, which sinking would form impermeable layer, which is resistant to a mechanical impact of stored material. When the insulation treatment were to be made on a dry disposal then an impermeable sheeting or sprinkling with a sealing substance could be used. This treatment however would be very difficult as the removal of draining arrangements could cause the pressure of floor water to rise and to damage the insulating layer.

(vi) In the open pits of the II-d type the storage of considered wastes will always lead to pollution of ground water. In case of the 1-st degree protection of the ground water, the disposal must always be insulated, no matter what type of waste is stored. Such an insulation may have a static character (sealing the floor and the slopes with impermeable sheeting or through sprinkling with substances setting the surface layer), or a dynamic character (in a form of a barrier of wells barring the contact of polluted and pure waters). When in the course of sealing the open pit will get filled with water, then there is no possibility of using the sheeting or sprinkling and only clay sealing may be employed. With requirement of the 2-nd degree of the ground water protection and when there is available waste material that is partly less and partly more permeable it should be stored selectively. The material weakly permeable (e.g. ash or flotation silt) placed close to the slopes and the floor of the disposal and the coarse material in the disposal interior. Then the permeability of the disposal will be limited by permeability of its outer layer, and this in effect will let a much smaller quantity of pure waters get into contact with the disposal. Moreover in this situation the pollutants as a result of ground water round flow, will have a tendency to concentrate in the uppermost section of the aquifer, and in a narrow belt of the horizontal dispersion.

12. Considering the planned disposal site to the protected part of aquifer this can be said:

- when the protected part is situated upstream of the ground waters flow then a few dozen meters as protection zone suffices, as the dispersion influence will not exceed this limit,

- when the protected part is situated in the zone of indirect influence of the disposal, then such disposal can be planned without a protection in the case of the 2-nd degree protection requirement, but this is not allowed when the 1-st degree of protection is required,
- when the protected part is located in the zone of direct influence of the disposal i.e. downstream, then this disposal planning cannot be entertained without providing protection, unless an appropriate forcast will indicate that this is permissible.

DESIGNING THE MONITORING WELLS AND THE CONTROL PERFORMANCES

1. Monitoring of the considered waste material disposals´ influence on the ground water quality can be performed so far only through a water sampling and analyses of sampled waters from monitoring wells, or shallow probes and, where possible from natural springs. There are so far no remote sensing methods which would enable measurements of the ground waters quality without a direct access to them. However some simple measurments could be made authomatically in the wells (e.g. temperature, conductivity).
2. In dependence on local geological conditions and on requirements of the scope of inspection, the monitoring wells can be one, two, or three -horizontal for separate aquifers. When within a drilled well is installed more than one pipe then is required a total insulation of particular aquifers.
3. When a necessity arises (e.g. in case of aquifer of great thickness) to determine the contents of pollutants in vertical zones, then a single pipe monitoring well suffices, for the zonal sampling.
4. When disposal is built as wholly insulated from the aquifer, the monitoring system should only control the disposal´s tightness. Then wells should be spaced along its circumference. The wells´

distance from the disposal verge should be of about 20 m upstream, 30 m in the intermediate zone and 60 m downstream the ground waters. The spacings between the wells should be smaller dowsstream, greater in the intermediate zone and greater ground water upstream. The respective numerical values can here be e.g. as 1:3:5. Localization of particular wells should be based on the analysis of effected sealing and on the hydrodynamic water heads′ distribution.

5. For the disposals which can be expected to influence the ground water quality the monitoring wells should be localized taking into account two basic hydrogeological criteria:

- the hydrodynamic water heads′ network
- the spatial structure of the aquifer and its transmissivity,

and also the reciprocal spatial relationship of the disposal and the protected zone.
When the entire aquifer is to be inspected then only few wells ought to be localized in the indirect zone. Whereas, ground water downstream consecutive wells should be placed at distances gradually increasing, e.g.:

1-st well	100 m
2-nd well	300 m
3-rd well	700 m
4-th well	1500 m.

The wells in this direction should be localized along the line of a stream with the greatest hydraulic dipping or when such a need arises within an area encompassed by extremal streams of the ground waters that could get into contact with the disposal.
When a subject of control should only be a determined part of the aquifer, then the monitoring wells can only be localized along one or two lines between the disposal and its protected part. Distances between wells can be similar as on given above example.

6. The monitoring wells should be drilled with a dry method, or a method of a water washing. Inadmissible is drilling with the application of other fluid washings, which may lead to a colmatation of the zone near to the well and give entirely erroneous conclusions. For, a phenomenon may take place, where the ground water flows round the zone of the well, hindering thus the exchange of water between the well and the surrounding aquifer. Recommended filter diameter is from 4 to 6 inches.

7. In the course of drilling the lithological log of all drilled layers should be determined accurately. Also the well levelling, the levelling of stabilized ground water table, and then the tests to determine the permeability and the specific yield of all tested aquifer layers should be executed.

8. The water sampling from monitoring wells should be effected after a previous removal from the well of a quantity of water corresponding in approximation to a 2 - fold volume of well. More intense removal of water from the well can change the natural regime of flow, whereas not removing the water may cause, that the sampled water was too long in contact with air or with the well casing. The samples may be collected by way of pumping or of a manual scooping.

9. For the investigations of unsaturated zone, also of compacted rock material characterized with very fine pores, one may use (only in the course of drilling) soil or rock material samples taken for centrifuging to obtain water micro-samples.

10. Taking water samples, their transportation, preservation, fixing, and the method of analyses performance should confrom to the obligating standards.

11. The water sampling connected with measurements of the water table position should be carried out with frequency of at least:

- disposals of the I (dry) type, once a month
- disposals of the II (wet) type, every 3 months.

12. For the disposals of I type, full analyses of waters should be made every 3 months (around 40 designations) and the remaining analyses treated as shortened (about 15-18 designations specified on the basis of filtrate analysis acquired in laboratory conditions), or according to standards, when such do exist.

13. Owing to frequency, particularly in developed regions, of significant fluctuations in quality of ground water from various activities (e.g. fertilization, dust emission) it is essential to possess reference data, which can be:
    - for the entire aquifer, a minimum of one year cycle of the ground waters' analyses' results before storage
    - in considering one part of the aquifer, the results of analyses from such a part, that does not undergo the influence of the disposal.

14. The test results should be periodically (minimum once at year) tabulated and discussed, to draw conclusions and to propose respective recommendations.

FURTHER RESEARCH

1. The recommendations regarding further studies should be divided into three groups:
    - investigations with the object to clarify the character of certain phenomena, so far insufficiently investigated,
    - investigations regarding the implementation of better methods of forcast elaboration,
    - observations of practical influence of the discussed wastes on the ground water's pollution on a larger number of disposals in order to acquire empirical and statistical data.

2. The studies on the clarification of phenomena insufficiently well known should comprise:

- investigations of the water balance of disposals (surface run-off, evapotranspiration, and underground run-off) for different types of waste materials and in various climatic conditions, in order to specify the quantity of precipitation waters leaching through the disposal,
- investigations of the flow of pollutants through the zone of aeration,
- investigations of the processes of sorption and ion exchange,
- investigations of vertical dispersion in porous media.

3. Investigations of improvement of forecast methods should comprise:
   - elaboration of methods of the ground water table recognition without necessity of drilling monitoring wells,
   - preparation of mathematical methods of modelling all phenomena affecting the pollutant migration through porous and fissured media,
   - preparation for the above methods of accomodating programs easy to modify and to check, taking into account differences in the phenomenon course for various ions.

4. Investigations of a practical course of the phenomena should be based on the assignment of about 10 disposals of coal mining refuse and coal fired plants ashes, situated in various hydrogeological and climatic conditions and their inclusion into systematic, long term observations. The observations should begin before a commenced storage, and last for at least 5 years.
   Prepared beforehand for these disposals should be qualitative and quantitative forecasts of their influence on ground water quality. These prognoses should be currently compared with actual results and correspondingly verified. On such disposals should also be performed investigations mentioned in pts. 2 and 3. The method of the investigations performance on all ten disposals should be coordinated by one and the same person, and the results periodically compared.

SECTION 4

DISCUSSION OF THE PROJECT PROBLEMS ON THE BASIS OF WORLD LITERATURE

METHODOLOGY OF THE LITERATURE COMPARISON, AND GENERAL DISCUSSION

To undertakie the project planning for both the field and laboratory research, and then determine their scope and methodology, the work began with gathering and analysing the literature connected with the subject matter. The object was to avoid work, which was already performed, and not to look for solutions which were already solved. Also there was the wish, to use all eventual experiences accomplished during other research work and other projects, as well as indicatie for further research those issues which had not been investigated as yet.

Around 140 papers were gathered, containing the basic compendium of knowledge connected with the propagation in an environment of ground waters of pollutants derived from wastes disposals. For a list of this literature see section No. 9. The specification of bibliography was prepared in alphabetical order including a berief review allowing the user to determine the appropriate position. This characteristic concerns:

Language in which a given position is available.

Type of paper - classification of references was made as follows.

1) general - the significance of the issues, the state of the organization, and its management in particular countries,

2) theoretical - the theory of physical and chemical processes taking place in connection with movement of miscible liquids in porous media (i.e. problems of convection, diffusion, dispersion, absorption, ions exchange etc.),

3) methodical - the manner of field work performance, field and laboratory tests and also computation methods (i.e. the way of drilings' execution and observations' performance, sample taking, their preservation, transportation, employment of analytical methods, also the ways of modelling etc.),

4) regional - a description of actual cases, which happened at a given time and place, and which are giving certain conclusions of a general nature, presenting an instructive case for the specialists engaged on similar problems.

Some of the papers were included into two groups, due to the contained elements e.g. the regional and methodical, or theoretical and methodical.

Application - due to progressive specialization, not only from particular persons, but also from particular organized groups and even of entire institutions, the usefulness of numerous papers is limited to narrow objectives. Various papers concerning the problem may have various "addressees". From this point of view a classification of literature was made, that may find application for the:

1) General knowledge of issues, and addressed to persons engaged in the field of administration, management, determination of directions of activity and general supervision.

2) Scientific research concerning narrow and detailed problems that can find application by institutes conducting scientific - research on particular aspects of a problem.

3) Planning and design works connected with the selection of sites for waste disposals, determination of technology and conditions of storage - with designs for the field tests and the monitoring systems.

4) Construction works connected with technical details, i.e. methods of storage, execution of monitoring wells, sampling etc. Part of the reviews can find application in various types of operations, and such papers are provided with two index numbers. E.g. some papers may, owing to their content, find application in both the design and execution works, or in scientific research and designing.

Evaluation of usefulness - the reviews of the literature were prepared for various requirements describing very different problems, which in different ways impact the subject matter of this project. Therefore the usefulness varies. Amongst the analysed papers three groups were distinguished:

1) The very important ones - which contain fundamental data, indispensable for understanding the problem, and the knowledge of which is a condition for work on the selected problem.

2) Useful - which contain a useful material affording a better understanding within the framework of a selected problem.

3) Partly useful, in which particular fragments contain material of contributing character, in which one may find analogy to the problems under study.

Substantial analysis of the state of knowledge in the fields connected with the project will be discussed in the next part of the report. However the following may be stated:

1) The summary of world literature indicates that no one was conducting identical research to this project. The majority of papers deal with different types of waste, mostly municipal, industrial agricultural etc.

2) Almost all analysed papers discuss one aspect to the issue: particular papers concern e.g. the chemical processes occuring during storage of particular wastes, the phenomena of diffusion or dispersion, the water balance of the waste disposals, processes taking place on the front of fluids mixing, mathematical modelling etc.

   No one paper contains a complex presentation of all problems, connected with waste disposal and influence on the ground waters, with consideration for all factors causing the phenomena.

3) Countries, in which most attention is devoted to the problems of this type of wastes'influence on the ground waters, and in which the research work on these issues is most advanced are: the U.S.A., France, West Germany, Poland, England, Soviet Union.

CHEMICAL CHARACTERISTICS OF COAL MINING' AND POWER - PLANTS' WASTES

Studies of the chemistry of the wastes were carried out on various types of waste material in very many countries.

Two groups of problems can be distinguished here:

The first group compose problems of methodology for conducting these investigations.

The second group is the chemical characterization of particular kinds of waste material.

As far as the first group of problems is concerned, employment of methods of standard chemical analysis are used. However, the methods of acquisition of the analytical material are different. Apart from the normal analysis of the tested solid substances, also employed are various types of arrangements used to obtain of leachates from waste material. Various filtration columns are used from the diameter 4 cm and length about 30 cm, through the medium ones with diameters of an order 10-20 cm, and lengths from 80 cm to 1,5 m, to the very large columns with diameters to 1 m and lengths to 5 m. The last ones serve to test the chemistry of waste leachates in conditions approximated to natural. Containers are also used for the tests on a semi-technical scale with dimensions of 2m x 2m x 2m filled with various thickness'layer of tested wastes. In the majority of the described cases the columns or containers are filled exclusively with the waste material without any other added materials, imitating the layer underlaying the disposal of the investigated material. The already existing disposals are also being used to investigate the chemistry of the leachates. In these cases the samples were taken from pits or trenches specially constructed for this purpose.

Material placed in the columns or containers was washed with water, or in an artifical way (obtained through sprinkling), or exposed to the influence of natural atmospheric conditions. This last method is employed in cases of large tanks with waste material.

The methodology of washing the waste material with water is used in two main quantitative variants.

In the first case the washing process is carried out either with an amount of water reflected by the permeability of the washed refuse, or according to programmed time of contact of this refuse with the leaching water. Then in leachates is acquired the maximum concentration of pollutants possible in optimum washing conditions, and the results can be achieved in a comparatively short time.

In the second case the sprinkling of refuse is employed with a limited quantity of water, corresponding e.g. to the amount of expected precipitation. The investigations of this type are long lasting (the results are achieved after 3-6 months'time), but the results quantitatively may be more close to the actual ones as expected in nature; although also here their deformation can be significant (due to dimensional differences). In such conditions, especially when the performed investigations comprise the acquisition of leachates from an unsaturated zone, (e.g. the underlining of the waste disposal), lysimetric equipment is being used for sampling.

The second group of problems is the chemical character of particular types of waste material. Leaving out initially the discussion of other types of wastes different from the ones being the subject matter of the project, i.e. the of coal mining refuse (gob) and coal - fired power plants ashes, one may say that even this group is showing significant qualitative and quantitative diversification. These differences ensue from different geological conditions of the formation of the coal deposits, finding their reflection in different mineralogical and chemical composition, both of coal and of accompanying sterile rocks. One deposit may typify coal and sterile containing large admixtures of sulphur compounds, the other a significant content of chlorides. The quantities of occurring heavy metals may also be different. Therefore a detailed analysis of literature on this topic indicates, that for the many exploited deposits there are many types of refuse which from the chemical point of view can occur in the practice of their storage. These differences, sometimes very great, influence in practice only one group of factors stipulating the course of the considered phenomena, namely the reactions taking place during leaching of disposal and between the leachates and the natural ground water, or with the soil skeleton of the medium through which they migrate. However one is quite sure that the waters in contact with ashes coming from the coal fired power plants and also with wastes coming from the dry and wet separation of the coal are always polluted. The presentation here of detailed numerical values, is not valuable as these are too diversified to be of use as a practical information. One can mention though, that the natural water contacting the above mentioned wastes may indicate an increase in the content of particular basic components as below:

TDS - up to 150 times
Chlorides - up to 200 times
Sulphates - up to 100 times
Light metals - up to 100 times (sodium up to 200 times)
Heavy metals - up to 250 times

MIGRATION OF POLLUTANTS THROUGH A ZONE OF AERATION

In the case of the disposal situated above the ground water table, the washed pollutants are passing first through the zone of aeration. Investigations of hydraulic phenomena occurring in this zone are a new domain and so far their significance was underrated. This causes that number of problems connected with the flow of liquid in just this zone do not have till now adequate mathematical description. In the study area the issue is additionally complicated by facts such as:

- the disposal itself is also unsaturated, with an extremally miscellaneous character of hydraulic permeability (formations from big size stone fraction to silt fraction deposited in disorderly fashion)

- feeding the disposal with water is of irregular character (dependent on the frequency and intensity of precipitation)

- the pollutants are transported also in the form of suspension which in the bottom part of the disposal and in the near to the roof portion of aquifer are undergoing the filtration, and can induce a sedimentation of fine particles in the pores of the porous medium and cause the formation of sealed layer

- pollutants filtrating through the unsaturated zone have the behavior different from pure water (amongst others e.g., different surface tension than of clear water).

The above complications make impossible a practical quantitative description of process and demand a qualitative explanation. The flow in the unsaturated zone depends on the following factors:

- the level to which the pores of the soil are being filled with liquid
- rates of pressures and their distribution
- the values of temperature and their distribution
- physical and chemical characteristics of the porous medium
- physical and chemical characteristics of the considered liquid - in our case the polluted water.

These factors largely depend on climatic changes, which additionally complicate the whole process.
However, lets consider some of these for their influence on the course of the phenomenon.

In the zone of aeration there can be distinguished three sub-zones:

- the upper zone, in which a dominating phenomenon is the evaporation
- the intermediate zone
- the boundary zone, where the capillary rise takes place.

In these zones one can distinguish the following states of the soil moisture:

- structural state, in which the liquid particles are chemically bonded, and cannot be removed without changing the character of the solid state
- absorption state, where water linked with the molecular forces occuring among the particles of water and the solid
- funicular state, in which the interfacial spacesare filled with water irregularly
- capillary state, where all spaces of pores of capillary sizes are filled with water.

Depending upon local conditions, the vertical reach of particular phases of wetting can be different and may lie in very wide ranges, that create also very variable conditions for the horizontal flow in the zone of aeration. Apart from the factors characterizing the medium, the vertical reach of particular phases is influenced by the fact whether the ground water table is rising (the capillary zone is lower), or whether is drawing down (the capillary zone is higher).

The influence of temperatures is a factor less important, and therefore will not be discussed.

Important factor are the physical and chemical properties of the porous medium. Apart from the basic features, which are the porosity and the dimensions of pores, (possible to determine in categories of quantitative description), also important is the shape of particular grains of soil and their surfaces' roughness. For the last two values there is a lack of method for their computations, and an application of analogy with the capillaries leads to oversimplification. Also a qualitative determination of a so variable parameter, as is the chemical character of medium, is practically not yet possible. No less essential factors influencing the flow in the unsaturated zone are the physico-chemical characteristics of the liquid. And so, e.g. saline water has a higher surface tension, than pure water (although the differences are not great), and moreover the phenomena differently operate on the contact line between the liquid phase and the gaseous phase in a saline medium. In such conditions the salt accumulates in the upper zone of the contact.

As appears from the above short description of the phenomena accompanying the flow of polluted water through unsaturated zone, these occurrences are extremely complicated and conditioned by great quantity of factors variable in time. A description of these factors and their quantitative interdependence is to the end practically impossible, although attempts to find basic dependences are being made (Stallman 1970). These problems however are not the subject matter of this project work, and although do affect the course of the phenomena under study, they are only indicated here. Due to the nature of the project these problems will be included in final results without making their quantitative separation. Their presentation will be useful because they also do influence the investigated final effect.

These phenomena were also confirmed by ground model research conducted under this project, and discussed in the section 8.

THE FLOW OF POLLUTANTS WITHIN THE AQUIFER

The waters polluted in contact with a disposed waste material flow into the aquifer directly when the disposal is placed below the ground water table, or indirectly through the zone of aeration when the bottom of the disposal is positioned above the ground water table.

From this moment the course of migration starts to be influenced by quite different physical and chemical factors.

Among the physical factors two basic groups can be distinguished:

- one group are factors of a hydrogeological nature, such as permeability of the aquifer, hydraulic gradient, structural geological forms etc;
- second group make factors such as the dispersion and diffusion.

Both these groups are interrelated however, and the final effect is their common resultant.

In the case study the polluted waters and the natural ground waters are wholly miscible, so the understanding of phenomenon of displacement of the miscible fluids in the porous medium is necessary for the comprehension of the entire problem.

First investigations of the displacement of miscible liquids in a porous medium were conducted by Slichter in 1905, who was injecting salt solution in to a well and then observed the time of its appearance in a neighbouring observation well.

After a longer break similiar tests undertook Scheidegger in 1954 but on a much larger scale. The tests have shown that mixing of two miscible liquids in a porous medium depends on the rate and distribution of the stream velocity in this medium and on the geometry of its pores. This mixing however was much more intense than could be credited to a molecular diffusion and was termed by him as dispersion.

Scheidegger proposed a description of the dispersion process in a formula of convection - diffusion in which the coefficient of dispersion substitutes the standard coefficient of diffusion. In the first papers concerning this problem a coefficient of dispersion was used in a scalar form. Following this de Jong (1958) introduced separate conceptions of the ccefficients of lateral and longitudinal dispersion, and Bear (1961) proposed the use of dispersion coefficient as a symmetric tensor of the second rank acquired from the contraction of the fourth rank tensor, which is the function of flow. The further stage of the study of this phenomenon was a conversion made by Shamir and Harleman (1966) of a Cartesian form of the convection - dispersion formula in an equipotential system of coordinates (being a function of stream). Numerical representation of the dispersion in ground waters was given by Redell and Sunada (1970).

All the reviewed research can be divided into 4 groupd, described as follows.

Theoretical studies

These studies were oriented to the explanation of the fundamentals of the dispersion phenomenon. They attempted to define the dispersion coefficient in relation to the characteristics of a porous medium, to the filtrating liquid and to the velocity of flow. Lets take for example a simple case. To a column containing a saturated porous medium was axially injected a portion of polluting solution of a dye. The center of this portion moves along the axis of the column ($r = o$) with an average velocity V_3. With time t the sizes of this pollution begin to increase, and mixing with the ambient initial fluid will spread both in the direction parallel to the axis (x_3) and in perpendicular direction (r). Variable concentration (c) of the dye is a result of both diffusion and dispersion. Diffusion is a direct result of a heat activation of particular particles. Dispersion in a porous medium is a process of mechanical or convective mixing, which follows in consequence of displacement of the particular particles of fluid with various velocities through the irregular porous channels and along intricate microscopic, structural routes of flow. Dispersion causes a variability in concentration similar to that caused by the diffusion, although this variability, as can be seen, is caused by different physical phenomena.

In the investigations of the dispersion process various models of porous media were used.

On the basis of studies as made on a cluster of capillaries by Aris the following formula for the coefficient of effective diffusion was derived:

$$D = D_d + T \cdot \frac{r^2 \cdot v^2}{D_d} \qquad (4 - 1)$$

where: D_d - coefficient of molecular diffusion
T - coefficient dependent on the shape of capillary cross - section
r - radius of the cross - section
v - value of the velocity vector.

Other theoretical approximation is based on a statistical model of microscopic movements of fluid particles and on averaging these movements in order to obtain macroscopic description of the dispersion on this base. Scheidegger (1954) disputed the phenomenon of molecular diffusion and propounded a theory of random routes widening this to a three dimensional model. However, assuming the same probability of the movement in optional direction he acquired also the coefficient of dispersion of the same value in all directions. This is obviously incompatible with the real course of the phenomenon.

Josselin de Jong (1958) moved much further, applying the approximated statistically phenomena and obtained a coeficient of dispersion as an anisotropic value - greater in the longitudinal direction and smaller in the lateral direction, of the movement of the stream.

Following this, Saffman (1960) introduced to the statistical model of de Jong, the phenomenon of molecular diffusion achieving for both these phenomena a common solution.

A subsequent step was the introduced by Bear expression of tensor of dispersion, as average function of a distance covered by a tracer in the medium. Bear had indicated that the coefficient of dispersion Dij is of the second rank, tensor and a linear component of velocity

$$D_{ij} = E_{ij\,mn} \frac{V_m \; V_n}{V} \qquad (4 - 2)$$

where: Eij mn - coefficient of dispersivity as a value characterizing the properties of the medium

$\frac{V_m \; V_n}{V}$ - tensor reflecting the linear effect of velocity.

On the basis of the above Scheidegger stated that the coefficient of dispersivity is a fourth rank tensor of 81 components, but owing to the symmetry of certain characteristics the quantity of these components can be reduced to 36.

In the following stage of research some scientists (Scheidegger and de Jong) proposed to describe the dispersion of the tracer in the stream of fluid in a saturated homogeneous porous medium with a differential equation:

$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial x_i} \left[Dij \frac{\partial c}{\partial xj} - V_i C \right] \qquad (4 - 3)$$

where additionally:

c - concentration of the tracer

t - time

V_i - component of velocity vector in a system of rectangular coordinates

x_i $(i = 1,2,3)$ - coordinates in the space system.

Following this Bachmat and Bear (1964) gave a similar solution for the system of polar coordinates composed of equipotential lines and of lines of streams.

Analytical solutions

Analitical solutions are based largely on analogy between the phenomenon of dispersion and the phenomenon of the heat propagation. For the consideration of phenomenon of a longitudinal dispersion let us take a case of a semi-finite column $(x_3 > o)$ filled with homogeneous and isotropic material where on one end of the column $(x_3 = o)$ is placed a flat source of the tracing material. The flow with a constant yield q is maintained in the x_3 direction.

For the isotropic material the axes of dispersivity tensor agree with the vector of velocity. In this way the equation (4 - 3) reduces itself to the form:

$$\frac{\partial c}{\partial t} = D_L \frac{\partial^2 c}{\partial x_3^2} - V_3 \frac{\partial c}{\partial x_3} \qquad (4 - 4)$$

where additionally: D_L - coefficient of longitudinal dispersion. Initial and boundary conditions are given through:

$$C(0, t) = Co; \quad t \geqslant 0 \qquad (4 - 5)$$

$$C(x_3, o) = 0; \quad x_3 \geqslant 0 \qquad (4 - 6)$$

$$C(\infty, 1) = 0; \quad t \geqslant 0 \qquad (4 - 7)$$

Later on Ogata and Banks (1961) used Laplace's converted functions to obtain solution:

$$\frac{C}{Co} = \frac{1}{2}\left[\operatorname{erfc}\left(\frac{x_3 - V_3^{t}}{2\ D_L^{t}}\right) + \exp\left(\frac{V_3\ x_3}{D_L}\right)\operatorname{erfc}\left(\frac{x_3 + V_3^{t}}{2\ D_L^{t}}\right)\right] \qquad (4 - 8)$$

where: erfc $(u) = 1 - \operatorname{erf}(u)$. (4 - 9)

They had shown that the second element of equation 4 - 8 can be omitted in majority of cases. E.g. when $D_L < 0.002\ V_3 X_3$ then the maximum error that could cause the omission of the second element may not exceed 3 %. Therefore, with the exception of an area directly placed by the source of the pollutant, an approximated solution will be given with the equation:

$$\frac{C}{Co} = \left[\frac{1}{2} \quad \operatorname{erfc}\left(\frac{x_3 - V_3^{t}}{2\sqrt{D_L - t}}\right)\right] \qquad (4 - 10)$$

In the examination of the longitudinal and lateral dispersion we will consider a case of a rectangular column of longitudinal dimensions $(o < x_3 < l_3)$ and lateral dimensions $(o < x_2 < l_2)$. Source of the tracer occupies a portion of top surface of the column of a certain width (b). In this situation the phenomenon will occur for both longitudinal and the lateral dispersion. Assuming the homogeneous and isotropic medium with one directional flow in the x_3 direction and by $\partial c / \partial x_1 = 0$, then equation 4 - 3 will take the form:

$$\frac{\partial c}{\partial t} = D_L \frac{\partial^2 c}{\partial x_3^{\,2}} + D_T \frac{\partial^2 c}{\partial x_2^{\,2}} - V_3 \frac{\partial c}{\partial x_3} \qquad (4 - 11)$$

In this case the initial and boundary conditions are given with:

$$c\ (x_2,\ o,\ t) = C_o;\quad o \leqslant x \leqslant b;\quad t > o \qquad (4 - 12)$$

$$c\ (x_2,\ o,\ t) = 0;\quad b < x_2 < l_2;\quad t \geqslant o \qquad (4 - 13)$$

$$\frac{\partial c\ (o,\ x_3,\ t)}{\partial x_2} = 0;\qquad t > o \qquad (4 - 14)$$

$$c\ (x_2,\ \infty t) = \text{limitary} \qquad (4 - 15)$$

$$c\ (x_2,\ x_3,\ o) = o;\quad o \leqslant x_2 \leqslant l_2;\quad x_3 > o \qquad (4 - 16)$$

For this case Harleman and Rumer (1963) proposed a simplified form giving an approximated solution.

$$\frac{c}{c_o} = \frac{1}{2}\ \text{erfc}\left[\frac{x_2 - b}{2\sqrt{\frac{D_T x_3}{V_3}}}\right] \qquad (4 - 17)$$

On the basis of these equations, in the next years, developed were analytical solutions for the following cases:

- Hoopes and Harleman for the radial dispersion
- Esmail and Kimber for variable tracer rate
- Dagan for a heterogeneous medium
- Shamir and Harleman for stratified media
- Bear and Todd for a non - steady flow.

Each of these issues constitutes a separate group of problems with many conditions and dependences and could be a subject matter of a separate paper.

Experimental tests

Empirical investigations for their object had mainly the determination of relationships, that could facilitate the computation of coefficients of dispersion in dependence on the characteristics of fluid and of medium. The experiments carried out by Ebach and White on a wide range of soil granulation, on different shapes of grains and Reynold's numbers permitted chem to derive for the $R < 100$ the following formula, for the computation of coefficient of longitudinal dispersion:

$$\frac{D_L}{V} = \alpha_1 \left(\frac{V_d}{\nu}\right)^{\beta_1} \qquad (4 - 18)$$

where additionally:

V - velocity of fluid
d - sizes of grains in the medium
ν - kinematic viscosity
α_1 - coefficient characterizing the porous medium
β_1 - coefficient characterizing the flow conditions.

Dependent on the employed research methods, various scientists obtained various values of these coefficients:

$\alpha_1 = 0{,}66 - 1{,}92$
$\beta_1 = 1{,}06 - 1{,}20$

Similar investigations made of the phenomenon of lateral dispersion allowed these same authors to derive the following formula for the computation of coefficient of lateral dispersion.

$$\frac{D^T}{V} = \alpha_2 \left(\frac{v \cdot d}{\nu}\right)^{\beta_2} \qquad (4 - 19)$$

where in this case the coefficients:

$\alpha_2 = 0{,}036 - 0{,}11$

$\beta_2 = 0{,}7$

Harleman (1963) on the other hand proposes linking of the coefficient of longitudinal dispersion with the permeability:

$$\frac{D_L}{V} = \alpha_3 \left(\frac{V\,.\,K}{\nu}\right)^{3} \qquad (4 - 20)$$

where additionally

k = permeability in L^2 units

$\alpha_3 = 88$

$\beta_3 = 1{,}2.$

In the framework of empirical studies, numerous scientists investigated the influence of molecular diffusion on the dispersion (Biggar, Nielsen 1964, Wats, Smith 1964, Bear 1968) arriving at the conclusion that it has no substantial claim but is only effective in a very fine - grained medium, and only in conditions of unsaturated medium in areas of so called dead pores (not taking part in the flow).

From the empirical studies, which allowed us to obtain the above formulas, and also from the studies that were fault finding (as e.g. Adams, who questioned without however a greater support from other scientists the dependence of the coefficient of dispersion on the velocity) one can draw the unequivocal conclusion, confirming that the coefficient of dispersion is a second rank tensor. One should realize however, that as up to now no adequate relationship was established yet for the wide range of, parameters of the flow.

The numerical solutions

Difficulties occurring with obtention of the required analytical solutions caused many scientists to turn in the direction of numerical solutions. Although the research in this direction is not so well advanced as is in the case of non - miscible fluids (crude oil industry) some results have been achieved already. The first serious achievement was the solution by Shamir and Harleman (1966). They developed an equation of dispersion as a condition of polar coordinates, assuming the velocity at every point as tangent to the lines of current and derived thus a one - dimensional equation in conditions of convection.

A further significant step was the derivation obtained by Reddell and Sunada of the following basic equations:

General equation of flow of two miscible fluids, was derived from a combination of equations of matter conservation, of Darcy equation and of an equation describing the relationship of pressure - temperature - volume - concentration.
With the assumptions of: 1) the validity of the Darcy law, 2) the onephase fluid, 3) isothermal conditions, 4) linear relation existing between the porosity and the pressure change, 5) volume not variable in time, they obtained following equation:

$$\frac{\partial}{\partial x_i}\left[\frac{p\,\Delta\,A_i\,K_{xi}}{\mu}\left(\frac{\partial \rho}{\partial x_i}+\rho_g\frac{\partial h}{\partial x_i}\right)\right]\Delta x_i =$$

$$=\rho_o\,\phi_o\,\Delta\bar{V}\,(\beta+c_F)\frac{\partial p}{\partial t}+\alpha\,\phi_o\,\Delta\bar{V}\frac{\partial c}{\partial t}+\rho_{pQ} \qquad (4 - 21)$$

where:

Δx_i $(i = 1,2,3)$	dimensions of the volume elements
ΔA_i $(i = 1,2,3)$	area of laterial cross-section of the perpendicular element x_i
$\Delta \bar{V}$	volume of element
x_i $(i = 1,2,3)$	rectangular coordinates
ρ	density of polluted liquid
K_{x_i}	permeability
μ	viscosity of liquid mixture
p	pressure of liquid
g	gravitational acceleration
h	elevation of element above the reference level
ϕ	porosity
β	compressibility of liquid
C_F	indicator of compressibility
α	indicator of ratio of concentration to density
C	concentration of polluting mass
ρ_p	density of mixed liquid
Q	yield of flow
ρ_o	relative density value
ϕ_o	relative porosity value.

Equation of dispersion - convection was obtained from equation of mass conservation by Fick, and from state equation in a shape:

$$\frac{\partial}{\partial t}(\phi \quad \bar{V}C) = \frac{\partial}{\partial x_i}\left[(D_{ij} + D_d\, T_{ij})\, \phi\, \Delta A_i\, \frac{\partial c}{\partial x_j}\right] \Delta x_i -$$

$$- \frac{\partial}{\partial x_i}(C\, V_i\, \phi\, \Delta A_i)\; \Delta x_i - C_p Q \qquad (4 - 22)$$

where additionally

Δ_{ij}	coefficient of dispersion as a second rank tensor
D_d	coefficient of molecular diffusion
T_{ij}	coefficient of the porous medium tortuosity
V_i	velocity of leaching in the i direction
C_p	concentration of pollutant in the polluted solution,

and auxiliary equations for the determination of the $\bar{V}_i$, ϕ, $\rho\, \mu$, T_{ij}.

Computer simulation of the displacement of miscible liquids was made by Reddell and Sunada. It was developed with allowed finite differences for each of the above equations for a two dimensional perpendicular relation and foundations were provided for a three - dimensional equation. The computer simulation was programmed in Fortran IV language on a CDC 6400 computer.

This program is composed of the following elements:

Program MAIN - receives initial data and directs the sequence of the operations.

Sub - program INICON assigns a uniform distribution of mobile points for every grid, with an initial concentration value of each point.

Sub - program READING reads or assigns corresponding values of permeability, porosity, viscosity etc.

Sub - programs INPRINT and MATROP print all initial values.

Sub - programs WRTAPE and RDTAPE serve as memory auxiliaries for data that can be introduced without making infringements to other programs, and enable reading and printing data, while the program proceeds.

Sub - program MATSOL controls boundary conditions and introduces respective changes.

Sub - program BSOLVE enables the employment of algorithm Band-solve for solving equations of matrix with the Gauss method of elimination.

Sub - program VELOCY calculates velocities and coefficients of the longitudinal and lateral dispersion.

Sub - program MOVPT computes on the basis of the VELOCY results the velocity components in each point and all displacement of points within the scope of the model.

Sub - program DISP computes changes in pollutant concentration in each point and time $t + \Delta t$.

Following this, the result returns to the sub - program MATSOL where the equation of pressures is again computed and the result printed and the whole process is repeated again for each consecutive step of time.

Similar approach to the problem presented also J. Bredhoft and G. Pinder (1973).

They adopted as a basis the equation of mass conservation in a form:

$$\epsilon \rho_i \alpha \frac{\partial p}{\partial t} + \frac{\partial}{\partial t} (\epsilon p_i) = \nabla \rho D \left(\frac{\rho_i}{\rho} \right) - \Delta \rho_i g + \sum_{k=1}^{s} R_{ik} + W_i \qquad (4 - 23)$$

and the equation of flow as:

$$\nabla \left[\rho \frac{k}{\mu} (\nabla p - pg) \right] + \sum_{n=1}^{n} W_i = p \alpha \frac{\partial p}{\partial t} + \rho_o \epsilon \beta \rho \frac{\partial p}{\partial t} + \frac{\epsilon}{V_o} \sum_{i=1}^{n} \frac{\partial m_i}{t} \qquad (4 - 24)$$

where:

ϵ - effective porosity of medium

p_i - mass per volume unit of the pollutant solution

α - compressibility of the medium

p - fluid pressure

t - time

q - unit yield of the fluid stream

D - coefficient of hydrodynamic dispersion

R_{ik} - velocity of formation of the polluting component expressed in units of mass per unit of volume of solution in unit of time

k - permeability

μ - dynamic viscosity

g - gravitation acceleration

β - coefficient of fluid compressibility

m_i - mass of factor "i" in V_o volume

$W_i(x,y,z) = \sum_{ji}$

ji - stream of mass of "i" component versus average mass velocity.

They converted the above equations for the requirements of an actual case of pollution with chlorides of an aquifer layer in the area of Brunswick town, obtaining a set of differential equations with which was solved:

- equation of flow with the method of finite differences alternated with method of iteration,
- equation of mass with the method of characteristics.

A further step in the rationalization of calculations was introduction by G. Pinder (1973) of Galerkin method of approximation of finite elements to obtain a transitory solution of equations describing the transportation of mass in a porous medium. In application of this method he approximated the distribution of pollutions with the chromium compounds in Long Island.

A practical description of a numerical model and of employed arrangements is given by Cearlock. The proposed system consists of three main types of models.

The informative model according to Cearlock permits one to determine a three - dimensional distribution of permeability with the help of minimum investigated points. This method is based on continuity of flow in a stream of current for a quasi - stabilized movement. The program formulated for two - dimensional systems assumes, that transmissivity equals to the product of the thickness of aquifer multiplied by the coefficient of permeability. For the flow in unsaturated soil medium a necessary thing is to have a mathematical description of the hydraulic characteristic of unsaturated soil media. This characteristic should comprise two relationships, namely:

- permeability in a function of capillary pressure
- moisture content in function of capillary pressure.

The first value is determined from a desorption curve, and permeability of a saturated medium. The coefficient of sorption being a function of a type of the soil medium and the ion concentration, can be obtained linking its value with the coefficient of filtration. Having at one's disposal the distribution, a certain quantity of a soil samples should be subjected to the investigation of the K : K_d relation, and in this way the spacial distribution of the K_d can be obtained.

The hydraulic models are divided into models of saturated and of unsaturated conditions. The model of the unsaturated conditions is based on a continuity of the inflowing and outflowing stream from an optional volume where the permeability, the hydraulic potential and the moisture are the functions of capillary pressure. The model is used for the unstabilized, the heteroionic saturated and unsaturated flows. The main input data are the relations: permeability - capillary pressure, and moisture content-capillary pressure. This program may work PST computer in an axially symmetric one, two and three - dimensional area. Model for the three - dimensional, saturated conditions was prepared on the UTT computer to work in an unsteady flow with variable permeability. According to the author a decrease with the aid of two independent models in the quantity of the input data was obtained, and reduced were the requirements concerning the magnetic memory.

The model of the water quality is based on an equation, that combines the characteristic of the fluid mobility and the reactions of polluting factor. Two models were prepared, describing the movement of macro - and microions with a considered convection, molecular and hydrodynamic dispersion and sorption. The input data for the model of quantity consituted:

- the flow velocity, derived from hydraulic models
- coefficients of filtration obtained through field and laboratory tests
- coefficient of sorption obtained from additional model of soil medium - sorption for the selected characteristic ions, or from laboratory columns´ tests.

Each of the models was divided into blocks in series and in parallel, enabling us to model particular elements independently of one another.

The above described integrated model arrangement is to be solved on a man - machine, computer system, composed of the:

1) boundary digital analogous converter
2) store display of CRT computer
3) teleprinter
4) digital computer PDP-9
5) printer with drawing and copying arrangement.

A graphical converter enables the introduction of maps and diagrams directly in to the PDP-9 computer memory. The CRT oscyloscope arrangement demonstrates current results and enables continuous cooperation of the operator correcting the input data. Any information about practical effect of this model are not available.

CHEMICAL ASPECTS OF A POLLUTANTS´ MIGRATION FROM WASTE DISPOSALS INTO SOIL MEDIA AND WITHIN THESE MEDIA

The increase in the content of various substances in natural waters is mainly effected by leaching from the surrounding environment, the dissolution of gases and the evaporation of water. The leaching occurs either through direct dissolution of minerals in water, or throhydrolysis of minerals not soluble directly in water. To the minerals soluble in water belong the direct (simple) salts. These are mainly the salts of Na, K, Ca, Mg of the hydrochloric acid, sulphuric acid and carbonic acid. Solubility of these salts is different and depends not only on the type of salt but also on temperature, and on the presence of ions in water. Among the minerals not soluble in water, but undergoing hydrolysis the greatest significance have various silicates, aluminosilicates and ferrosilicons constituting about 75 % of the total minerals of the earth crust. Formed during the weathering in the presence of water and CO_2 are the carbonate and bi-carbonate salts of Na, K, Ca, Mg, or in suitable conditions sulphates and chlorides of these metals. Passing into water is also a portion of the contained in the environment Si, Al and Fe in colloidal form.

The described above phenomenon is termed chemical migration.

Factors determining the chemical migration of the elements include first of all its inner factors, i.e. the chemical character of the element itself, its capacity to form compounds with a varying degree of solubility, volatility, hardness etc.

A great influence on the chemical migration has the form of occurrence of the chemical element, the type of crystelographic lattice of a given chemical compound and its susceptibility to weathering and to dissolving.

Chemical migration of elements depends also on external factors, i.e. on conditions in which the migration of atoms takes place. In dependence on external factors the following kinds of chemical migration as a form of a matter movement can be distinguished:

- the biological migration connected with life processes on earth,
- aqueous migration connected with displacement of particles or ions,
- atmospheric migration connected with displacement of gases.

A more comprehensive discussion concerning the subject matter of the project requires here only the aqueous chemical migration to be considered. The intensity of migration of chemical elements is characterized only by those atoms of given element which become mobile in a given unit of time.

A general equation of migration intensity has this form:

$$P_x = \frac{1}{W_x} \cdot \frac{dW_x}{dt} ; \qquad (4 - 25)$$

where: W_x - total amount of atoms in a given element

dW_x - quantity of mobilized atoms in dt time

dt - time of observation.

The intensity of chemical aqueous migration is characterized by the coefficient of migration K_x equal to the ratio of content of given element x in dry mineral residue of water to its content in an environment leached by water.

$$K_x = \frac{m_x \cdot 100}{x \cdot n_x} \qquad (4 - 26)$$

where: m_x - content of x element in waters in g/l

n_x - content of x element in rocks in %

a - sum of substances dissolved in water in g/l.

The greater the coefficient of aqueous chemical migration, the more intensely is this element leached, and the more extensive is its aqueous migration in solution.

It appears from the calculations, that the coefficients of the chemical aqueous migration are related to one another in the same way as is the intensity of their migration.

For the evaluation of intensity of chemical aqueous migration a following gradation was used:

Determination of migration intensity	K_x value
very mobile elements	n . 10 to n . 100
easily mobilized elements	n to n . 10/n $<$ 2

mobile elements	0.n - n/n < 5
weakly mobile elements	< 0.0 n

To the very mobile aqueous migrants in all conditions belong the following anions: S , Cl, B, Br.
To mobile ones in all conditions belong cations: Ca , Na , Mg , Sr , Ra and anion F.
To the weakly mobile migrants in all conditions belong cations: K , Ba , Rb , Li, Be, Cs. Tl, and anions: Si, P, Sn, Ge, Sb, and the not dissolving compounds of elements Al, Ti, Zr, Tr, Y, Nb, Ga, Th, Se, Ta, w, Hf, In, Bi, Te.
To this group belong also platinum metals and gold, that hardly make any chemical compounds and appear in nature in a native state. Moreover a group of elements exists, whose mobility is strictly connected with the type of environment.
And so, cations Zn, Ni, Cu, Pb, Cd, Hg, Ag are showing intensive migration in an acid oxidising environment, and poor in inactive and alkaline waters.

Whereas, anions V, U, No, Se, Re migrate energetically when the environment is more alkaline. The Fe, Mn and Co are mobile in a reducing environment, and inert in oxidising environment.

The size of migration depends therefore on the chemical composition of waters, on the coefficient of aqueous migration, on solubility of compounds appearing in constituent, on the content of the element in environment, on the pH of water, on the oxidising - reducing character of water, on the capacity of elements to form complex and colloidal compounds.

Colloidal substances, which in time accumulate more intensely in an environment, fulfill an important role. One of the specific features of the colloids, having a great geochemical significance is the sorption and capacity to exchange able adsorption of ions. This characteristic is showing particularly in clay soils. Each material contains elements, which do not dissolve in distilled water, yet enter the solution on contact with the solution of an inactive salt. Here a portion of cations of natural salt is absorbed by the soil, and in its place are evolved from the soil other cations in equivalent amounts. These are the so called replaceable cations.

The quantity of anions in a majority of cases does not change.

Cations are also in various degrees absorbed and displaced by colloids. The interrelations existing between the composition of the solution and the composition of replaceable cations undergo the laws of a physico - chemical balance and depend on the solution concentration, the content of cations in it, on the electric charge of a given cation, on its radius, on polarizing characteristics etc.

The soils always contain a certain quantity of replaceable cations, whereby the cations of calcium and magnesium occur in almost all soils, and the cations of sodium, hydrogen and aluminium in only some types of soils. Total quantity of replaceable cations, i.e. the absorption capacity does not exceed on the whole 1 % of all ions.

The most abundant are colloid particles charged negatively. To these belong humus substances, silty minerals, ferrosilicons and hydroxides. They, apart from the Ca, Mg and K, can absorb also many heavy metals, such as Cu, Pb, Au, Ag, Hg and others.

Much less abundant are colloidal particles positively charged consisting of hydroxides of iron and aluminium, which are characterized with exchangeability features of anions Cl, SO_4^{-2} and PO_4^{-3}.

Most of the occurring exchange in soils is of cations Ca and Mg for Na and in reverse.

As an example: if the calcium - sulphate or the magnesium waters flow through clay rocks containing replaceable sodium then the cation of sodium passes into solution and waters from the calcium - sulphate become sodium - sulphate waters. When however sodium - sulphate waters migrate through rocks containing exchangeable calcium, then the sodium from the solution will displace calcium, which will form gypsum in a form of sediment with the sulphate ion, sodium instead will accumulate in a replaceable form in rocks.

R.E. Grim classifies in a following sequence the cations, which can pass from rocks into a solution by way of reaction of ion exchange, as Ca , Mg , H , NH_4 i Na .

In the effect of a so called dolomitization decreases in waters the content of Mg ions, and increases Ca ion content in conformity with the reaction $2CaCo_3 + Mg \rightarrow CaMg\,(CO_3)_2 + Ca$. In this way the soil sorption complex becomes a potential source of cations (more rarely anions), which may relatively easily be introduced into solution, although remaining in a solid phase. They possess a considerably greater migration capacity, than have the non - replaceable cations.

A sorption can also have an unexchangeable character, when the absorbed metals are strongly established in the crystalline lattices and do not pass back into a solution in the environment of salt solutions. Sorption plays an important geochemical role, as it decreases the migration properties of some elements and facilitates their passage from an unsaturated solution into a solid phase.

Next to the sorption a great significance is also attributed to ultrafiltration, which is based on a varying capacity of ions' passing through the layers impermeable owing to their different size. E.g., magnesium ions may filtrate easier than the larger from them ions of calcium.

Thus the chemical migration of elements in soils govern separate geochemical laws, which not always let themselves be subordinated to chemical laws.

In summing up one has to emphasize, that the dissolving capacity of water is very great. Also the natural waters, even the rain waters contain certain admixtures, which often increase the ability of waters to dissolve and to decompose substances from the wastes disposal.

Natural waters circulating in various geochemical conditions cooperate with environment and vary their composition and characteristics in time and in space. So the cooperation of water with the environment is based on the increase in content of various substances in water, on removing substances from water and on qualitative change in composition of substances dissolved in water.

Total content of dissolved substances in waters is, as from the above exposition can be seen, conditioned by a number of variable factors connected with the physico-chemical character of both the soil medium in the reach of which the migration occurs, and the physico-chemical character of the natural ground waters.

A detailed knowledge of phenomena occurring during the migration of elements requires therefore complex analyses and a determination of the content of each ion separately.

METHODS OF THE GROUND WATERS´ PROTECTION AGAINST POLLUTION

In a case where ground waters of a good quality should be protected, and are threatened with a pollution, and the storage of wastes in the existing open-pit cannot be avoided, it may be necessary to isolate the waste disposal which poses the pollution threat to the aquifer.

Literature only very sparsely discusses this issue from the environmental protection point of view. Nonetheless there are many positions dealing with sealing permeable soils for other purposes; mainly for the construction engineering.

For shallow objects (up to 40 m) in conditions of loose formations methods are employed using screens in the shape of narrow deep trenches (to 1 m wide) executed with shielding the ticksotropic suspension and filled with impermeable material.

For the objects with a practically unlimited depth, there are used methods of grouting the permeable formations with injected substances sealing the soil through the displacement of water contained in the pores and crevices and their substitution with this sealing substance.

Both of the above methods allow the construction of vertical screens.

In construction of horizontal sealings in hydrotechnics sealings, they are being used in the form of lining the water reservoirs with clay layers or with plastic sheeting.

Another solution mentioned in literature is a possibility of water reservoirs with sandy bottoms to be sealed through sprinkling the sands with substances, which penetrates the sands to a depth of a few centimeters, forming on their surface an impermeable layer. This solution is not being described in detail here as the employed substances have a patent claim.

The technical issues of sealing do not enter the main goal of this report, and moreover is broad domain in its own right. Therefore, it is not widely considered in this place. We will return to it in the course of this report where we discuss suggestions concerning the isolation of waste disposal from ground waters.

SECTION 5

PROGRAM OF RESEARCH WORK

In reference to the object of the project and to the actual state of knowledge and to technical and financial possibilities the following program of research work was undertaken.

The main part of the project constituted, the provision of two research waste disposal areas together with respective systems of monitoring wells. One of the disposals was supposed to have a capacity of 1000 m^3, and the other one 100 m^3. In the course of the project an opportunity occurred to take over for the investigations, in place of the 100 m^3, capacity disposal a much larger disposal with the capacity of about 800 000 m^3. This proposal was approved by the Project Officer, so in effect two disposals, were taken over for research one with the capacity of 1500 m^3, and the other one with the capacity gradually increasing (30 000 m^3 a month) to a total of 800 000 m^3.

Program of research work for the disposals anticipated:

- a quantitative and qualitative characterization of the disposed waste material
- meteorological observations comprising measurements every day of precipitation and temperature values
- drilling and installing monitoring wells with permeability determination

- surveys of the water table positions in monitoring wells at 3 weekly intervals during the first 15 months of observations' performance, and then with a *decreasing frequency*, *dependent* on conclusion drawn during the first 15 months time of observations

- collection of ground water samples from all monitoring wells for the laboratory determination of their physico-chemical characteristics in time intervals as given above.

Program of laboratory tests was devised to:

- determine the physico-chemical characteristics of waste material particularly in the aspect of leaching of particular components from it in an aqueous environment

- perform at three weekly intervals of physico-chemical analyses of waters collected from the monitoring wells with the determination of 19 basic characteristics (shortened analyses): color, smell, conductivity, pH, hardness, basicity, acidity, total dissolved solids, mineral and volatile, Cl, SO_4, N_{NH_4}, Ca, Mg, Na, K, Fe, Mn

- perform of every fourth series of analyses (i.e. approximately at three monthly intervals) as full scale analysis in the framework of which were additionally determined the N_{NO_3}, N_{NO_2}, phenols SiO_2, PO_4, Al, As, Cr, Pb, Cu, Zn, Hg, Sr, Cd, Mo, B.

Program of model research anticipated:

a) Demostration of certain general aspects of the course of the polluted flow occurrence in a porous medium, and which in available literature were described to a lesser degree than was required for the project needs, and the field tests in the projected scheme could not supply any information.

b) Develop a model for a large wastes' disposal area with the object of its verification in practice.

It was decided therefore to perform:

- tests on an analogous model of the Hele-Shaw type, of the phenomenon course of vertical propagation of pollutants leached from a large disposal with different permeability from the neighboring aquifer and in conditions of geometrical aquifer floor deformation
- test on a soil model of selected problems to demonstrate the influence of some factors on the shape of polluted zone
- tests, on an analogous model EHIDA type, of pollutants propagation in the region of one of the two experimental field site disposals, to provide comparisons for the field and the model observations, therefore to determine the usefulness of this method for prognoses of the investigated phenomena, and also for evaluation of the degree to which the final polluting effect in any optional point is a function of hydrogeological processes and to what is a function of such phenomena as sorption, ion exchange, dispersion etc.

In model tests the emphasis was placed on the investigation of the hydrogeological factors influence on the migration of pollutants and not on the details of the processes of dispersion, diffusion, sorption and others in propounding two assumptions:

1 - with large - dimensional objects these factors play generally a minor role as opposed by a point pollution,

2 - these processes are known quite well as described in section 4.

SECTION 6

RESULT OF TESTS ON THE DISPOSAL NO. 1

LOCATION , CLIMATIC AND HYDROGEOLOGICAL CONDITIONS

The experimental disposal no. 1 was placed at the bottom of an actually being in operation open pit mine of a stowing sand, (Fig. no. 1) planned to be filled with gob and ash beginning with the year 1982. This mine is situated about 150 km to the South - East of Wrocław. The excavated here deposits of sand form quaternary, fluvioglacial formations shaped as the variously grained sands containing silty and clayey intercalations. Thickness of this series amounts to 50 m. The elevation of the terrain in the region of the open pit varies within the + 195 to + 210 m limits above the sea level, and the initial ground water table on altitude of about 190 m above s.l. is indicating a tendency to fall in the NW direction. The open pit mine has a depth of 20-50 m and had induced a depressed water table to altitude + 165 to + 173 m above s.l. Within the limits of the open pit the depressed water table shows a decline from East to West similar to the general regional tendency. The experimental waste disposal is situated in the eastern part of the open pit, between an exploited wall and a draining ditch (Fig. no. 3,4), where the floor of the open pit has altitude of within 171,0 to 171,9 m above s.l. and only by the eastern fringe it has 173 m above s.l.

The direct subsoil of the disposal constitutes a layer of sand with thickness 1,2 to 2,0 m (Fig. no. 5), which only by its eastern fringe thins out and its thickness comes to below 1 m.

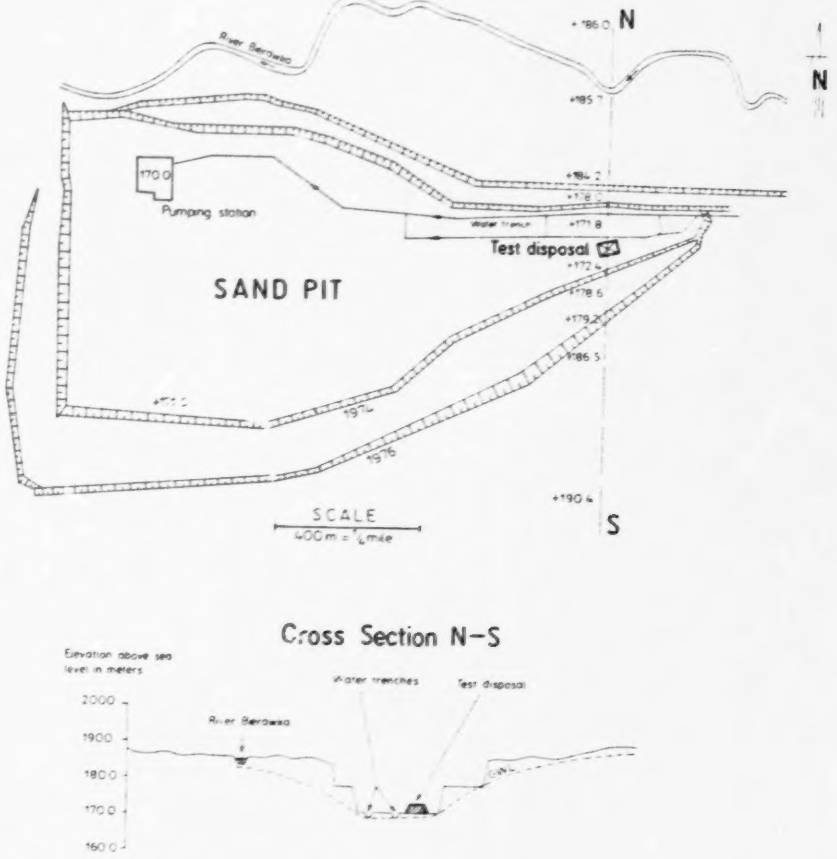


Fig. 1 SKETCH OF LOCATION OF TEST DISPOSAL №1

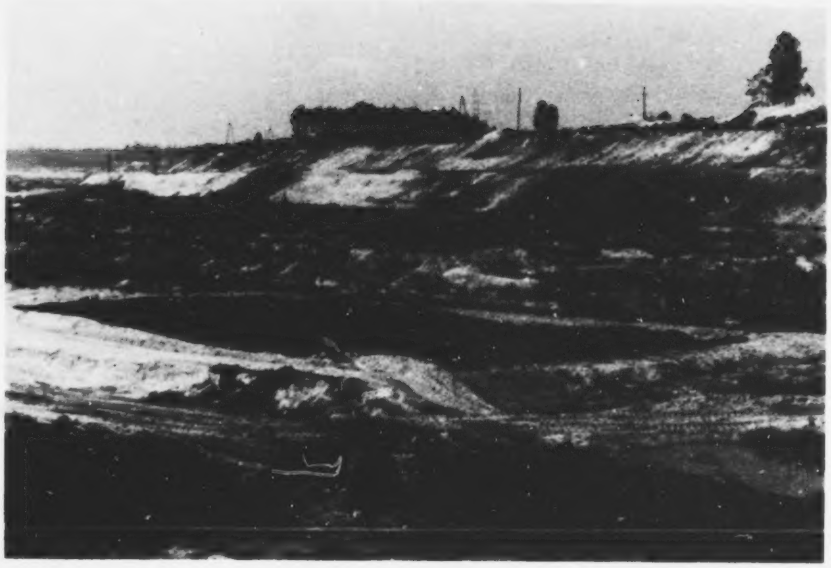


Fig. 2a. Disposal no. 1. General view.

Fig. 2b. Disposal no. 1. View of surface and monitoring wells

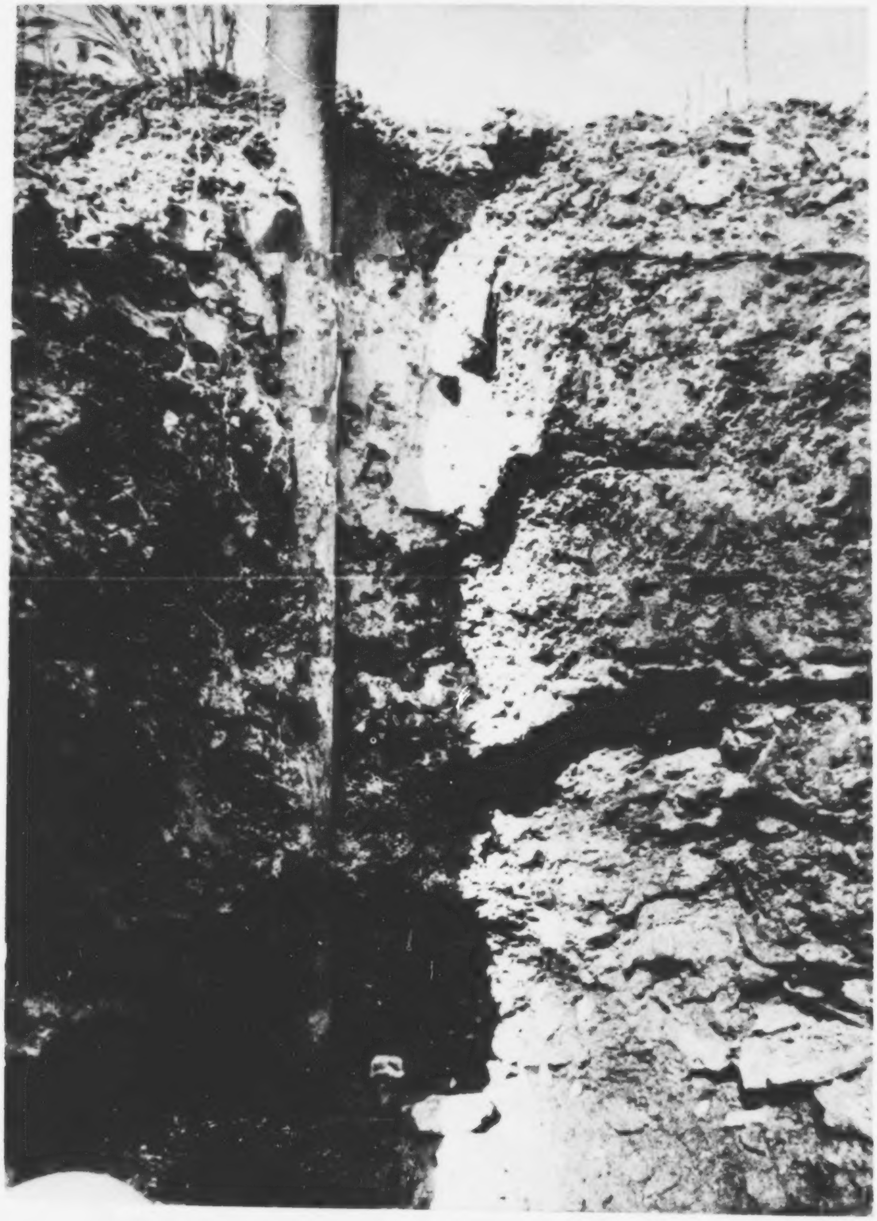


Figure. 2c. Disposal no. 1. Cross section of stored material along monitoring well. Excavation made 2-1/2 years after storage.

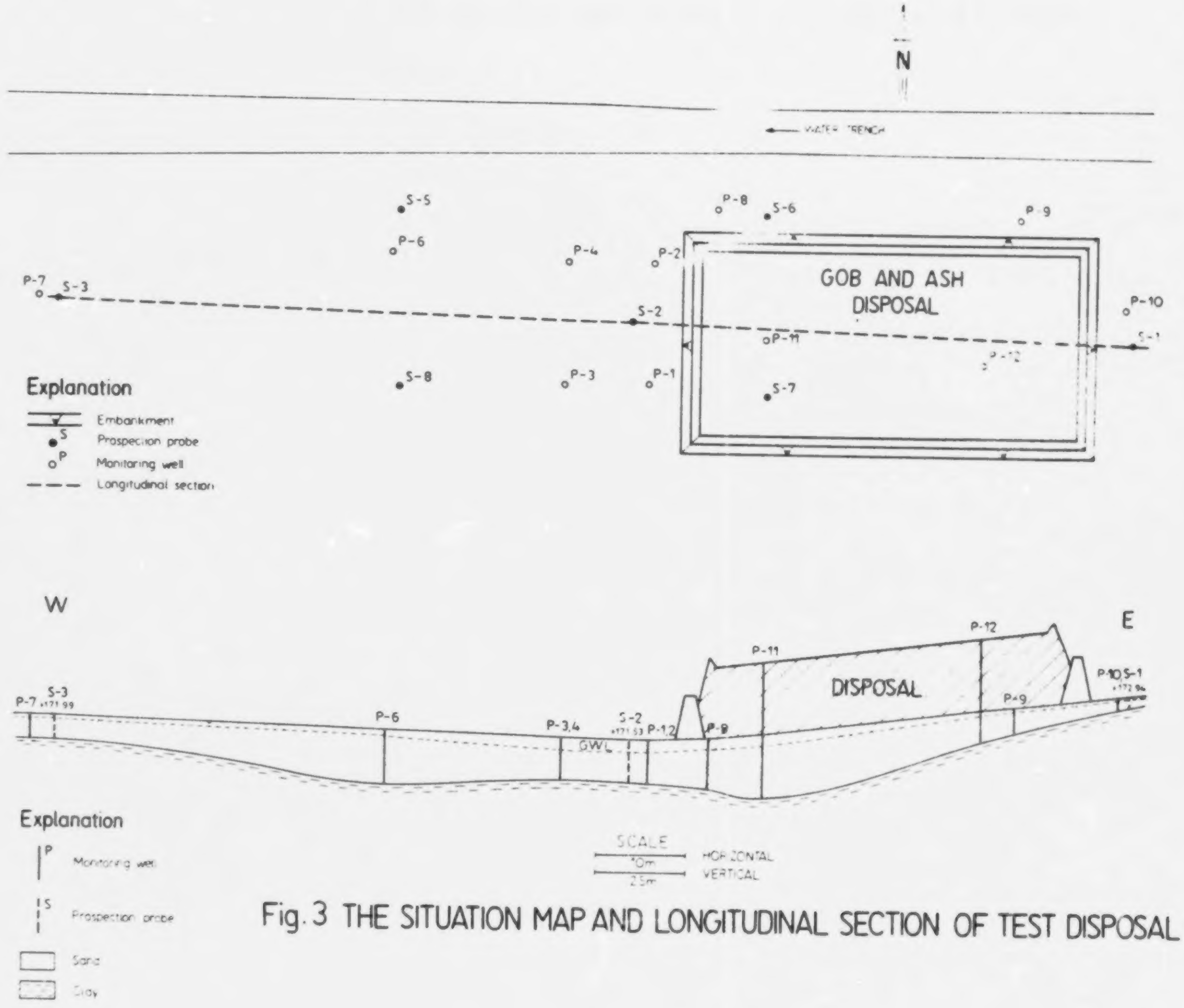


Fig. 3 THE SITUATION MAP AND LONGITUDINAL SECTION OF TEST DISPOSAL № 1

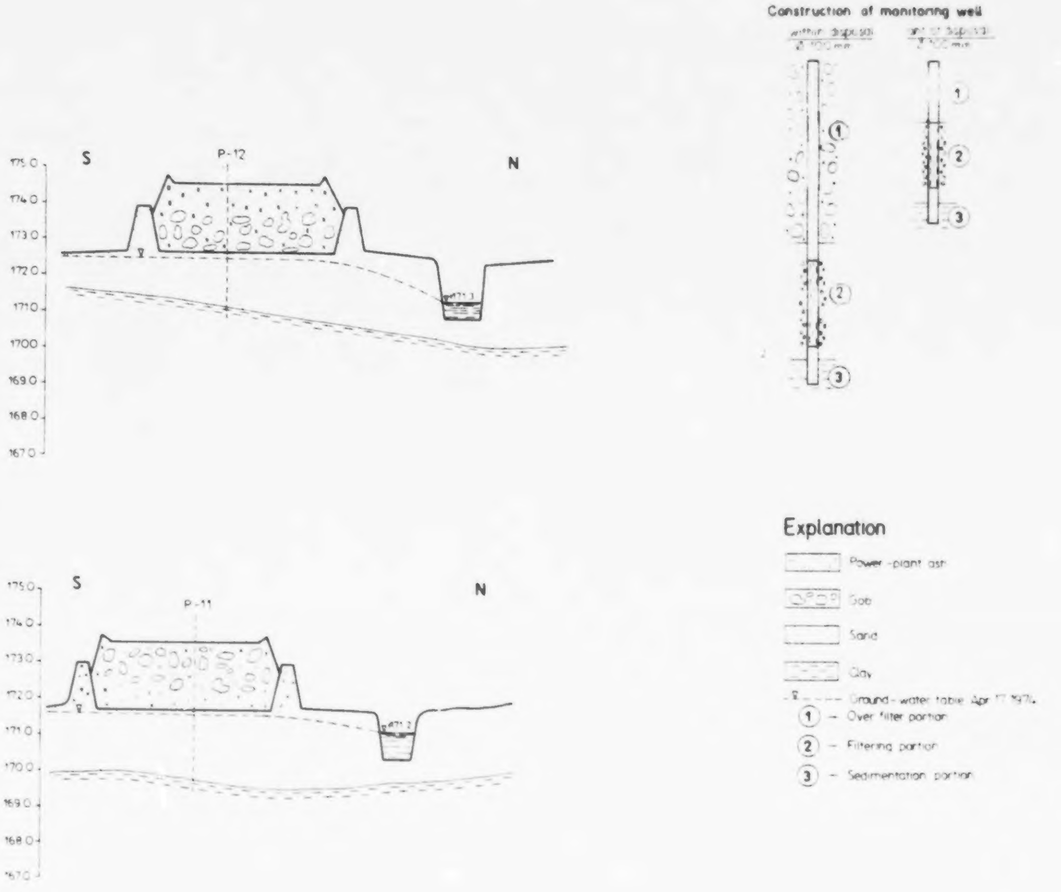


Fig. 4 DISPOSAL №1 CROSS SECTIONS AND CONSTRUCTION OF MONITORING WELLS

Outside the disposal the thickness of the sands is:

- in the east and the south-east direction decreases to about 0,5 m
- in the northern direction maintains at about 1,8 m
- in the western direction increases at first to about 1,7 - 2,5 m, and further on decreases to about 1,3 - 1,1 m.

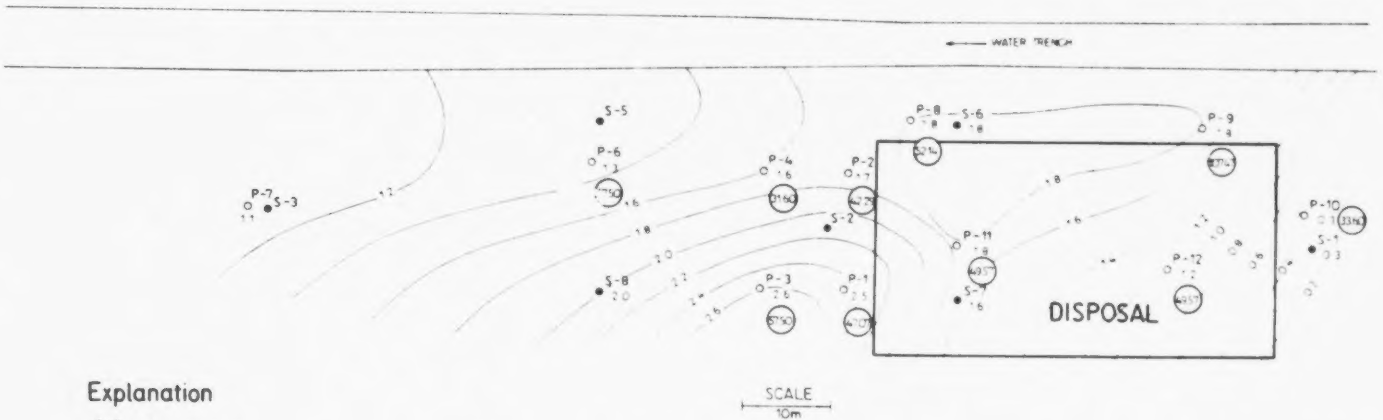
These changes in the sand thickness are the result of a delevelling of roof of the underlining layer of impermeable clays, with thickness exceeding 10 m.

In lithological respect the investigated formations are the coarsely grained, yellow - grey sands with a 15 - 20 % admixture of gravels, only in the well no. 9 the sands are passing into gravels with about 40 % admixture of sands. The coefficient of the sands permeability in a direct disposal's subsoil is k = 49,5 m/day, while in the neighbourhood the lowest values occur in eastern direction (k = = 33,5 m/day), highest values (k = 50 - 100 m/day) in northern direction, and intermediate (k = 30-50 m/day) in the western direction.

Appropriate values of the specific yield coefficient fluctuate within limits μ = 0,19 - 0,22.

The sand layer is in its entire thickness waterlogged, and the water table has a free character. The highest position of the water table was found to be beyond the eastern fringe of the disposal stack, with the elevation of about + 173,0 m above s.l. (fig. no. 24).

The water table at its lowest level is at the 15 m distance north and west from the disposal, with its elevation there being about 171,5 m above s.l. In particular wells the delevelling of the water table in time does not exceed 10 cm, which in approximation corresponds to maximum values of the precipitation intensity supplying this horizon (fig. no. 7). On the whole, the water table has its inclination from the south to north and to north - west. It means that from the side of the slope declines in the direction of draining ditch, and conforms with the direction of the run - off in the ditch. In this general tendency



Explanation

● S-1 Prospection probe

○ P-1 Monitoring well

0.3 Thickness of sand in /meters /

—1.0— Contour of sand thickness

Coefficient of permeability in ms /day

Fig. 5 DISPOSAL № 1. THE CONTOUR MAP OF SAND THICKNESS AND PERMEABILITY

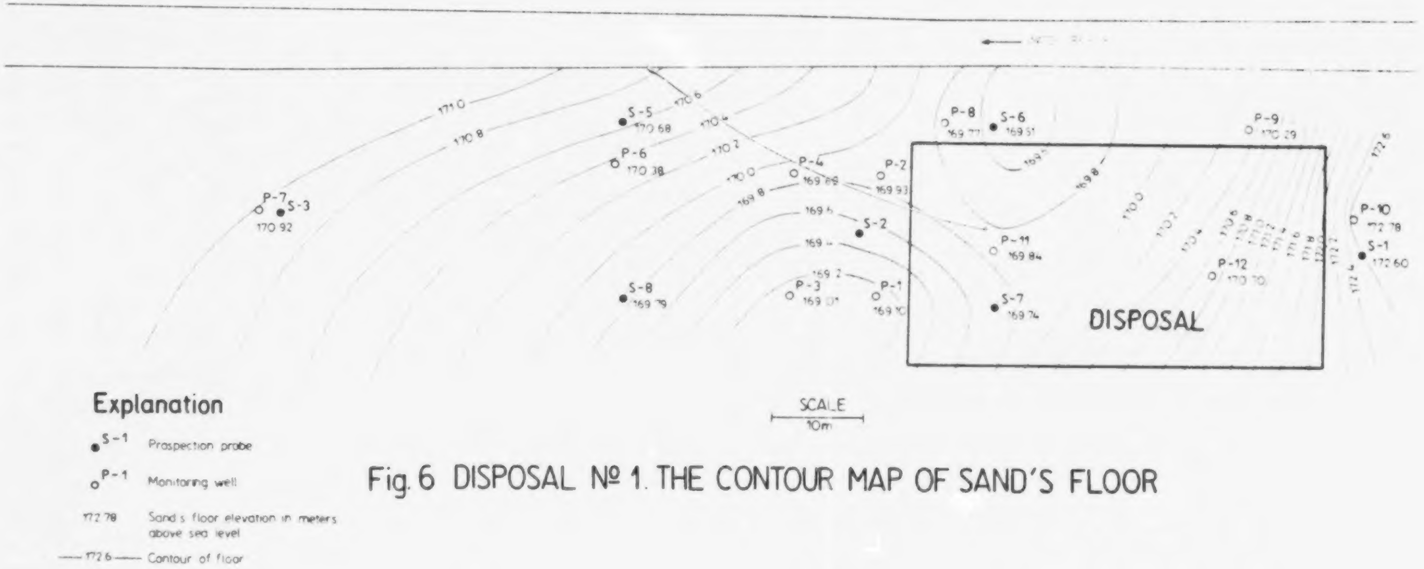


Fig. 6 DISPOSAL № 1. THE CONTOUR MAP OF SAND'S FLOOR

DISPOSAL NO. 1

THE AVERAGE DAILY TEMPERATURES

in C°

Table 6 – 1

Day	1 9 7 3		1 9 7 4											
	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1	-2,9	- 6,5	0,2	2,4	-0,2	8,4	12,4	13,6	16,0	20,2	14,0	7,3	3,0	2,4
2	-3,5	- 9,6	-0,9	3,7	0,6	9,3	11,0	14,8	14,6	20,8	15,8	7,8	4,0	5,2
3	0,2	-11,5	1,3	4,4	0,1	8,1	11,4	16,	15,4	19,5	17,8	6,7	4,3	8,2
4	3,0	- 2,0	1,6	1,8	2,0	7,8	11,6	14,0	13,3	22,4	14,0	6,8	3,6	4,8
5	6,5	1,2	4,0	1,0	3,5	8,3	10,3	13,0	14,2	19,2	14,4	6,2	3,1	4,2
6	6,6	1,3	0,2	3,8	0,3	8,2	9,1	12,3	18,2	16,0	17,3	7,0	2,3	2,1
7	4,4	2,6	-0,9	3,0	0,5	9,4	5,6	12,0	13,0	14,1	13,4	8,2	1,0	2,1
8	5,6	2,1	-1,0	1,3	0,0	7,7	7,0	11,2	12,0	18,4	15,2	8,2	-1,3	5,0
9	5,8	- 2,4	0,2	3,8	0,0	10,8	8,6	12,2	16,2	16,9	16,3	8,4	1,0	4,3
10	9,0	- 5,3	-3,3	8,0	1,0	11,0	8,2	10,6	15,4	15,4	15,1	6,9	4,7	5,1
11	7,6	- 5,0	-2,1	6,4	0,5	13,6	10,6	10,8	14,6	14,0	11,2	8,1	6,1	3,7
12	6,0	- 2,2	2,3	7,6	2,0	12,0	14,9	9,4	15,6	14,6	12,6	7,3	5,0	2,3
13	5,6	- 0,6	0,4	3,8	3,4	5,9	14,3	13,3	16,8	15,4	16,9	7,4	5,5	-0,2
14	4,2	1,4	-0,4	5,3	5,0	3,6	12,3	14,4	21,6	18,1	17,7	4,1	4,4	-1,2
15	2,2	- 1,2	0,0	5,3	5,2	4,0	10,9	14,5	17,5	23,2	15,4	5,6	7,2	-1,8
16	3,1	- 1,2	1,6	7,3	5,7	3,1	8,4	14,8	18,8	23,6	13,4	4,4	10,2	0,5
17	3,2	1,0	2,8	6,2	8,3	4,9	10,8	15,1	16,9	25,6	14,5	4,4	9,7	2,2
18	1,1	0,6	1,1	6,9	9,1	4,1	13,2	17,4	15,0	21,2	16,2	6,3	8,0	3,0
19	2,6	- 2,7	4,0	4,8	9,4	5,8	14,6	13,5	12,8	19,0	14,6	7,4	7,6	2,8
20	1,7	1,0	6,8	1,4	8,3	6,9	15,3	13,2	12,7	17,1	10,8	8,6	3,8	3,3
21	0,7	5,7	4,0	-0,9	14,3	6,4	13,4	13,5	13,5	16,4	11,9	5,5	5,2	5,6
22	0,1	6,2	-0,5	0,4	11,1	6,7	10,5	13,8	15,3	17,1	13,9	5,2	2,8	3,5
23	3,0	4,5	1,4	0,9	9,4	7,5	10,2	15,3	16,1	17,7	12,1	6,0	1,0	1,6
24	6,6	5,1	2,8	-0,3	-7,3	8,0	9,5	14,5	18,6	17,7	10,3	5,6	2,8	0,0
25	5,0	6,4	3,6	0,7	6,4	7,1	10,3	16,6	15,4	17,2	9,3	7,4	6,4	1,4
26	-0,7	1,9	3,7	-0,8	8,6	4,9	12,2	18,9	12,8	18,1	9,2	4,7	4,1	5,2
27	-1,2	2,0	4,7	-0,5	8,0	5,4	13,3	17,3	16,5	17,2	9,3	5,0	2,4	8,0
28	-3,2	3,1	3,0	-0,5	7,1	9,3	16,7	17,0	20,0	16,3	10,3	5,4	3,6	6,7
29	-3,5	3,5	3,1		10,0	11,6	15,6	16,2	19,8	17,8	7,3	3,8	3,4	9,8
30	-5,1	2,6	3,2		10,6	13,4	13,8	16,6	20,6	16,3	7,8	3,4	2,4	3,1
31		1,5	3,3		10,4		15,9		19,2	17,0		3,8		-2,0
Monthly average	2,6	0,2	1,6	3,1	5,4	7,7	11,7	14,2	16,1	18,2	13,4	6,2	4,2	3,3

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DISPOSAL NO. 1

THE AVERAGE DAILY TEMPERATURES

in C°

Table 6-2

Day	1975 I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1	2,3	2,7	1,9	2,7	9,7	8,0	12,0	17,8	18,6	18,7	4,5	3,8
2	3,5	4,3	2,0	4,4	11,0	6.8	19,0	16,5	19,3	15,4	5,8	4,0
3	4,0	1,0	5,2	4,5	9,0	11,3	18,7	17,2	19,4	14,8	7,1	5,2
4	1,5	-1,8	6,0	7,8	8,6	11,7	19,2	18,7	19,5	13,0	7,5	3,0
5	4,4	-3,0	7,5	11,6	10,4	10,5	19,5	16,7	16,2	10,4	6,8	3,9
6	6,0	-3,1	7,6	11,9	14,0	10,8	19,8	18,3	14,7	12,0	6,5	4,6
7	6,2	-2,2	7,2	6,5	16,7	13,0	17,9	20,4	15,3	11,2	6,7	1,3
8	0,9	-1,3	8,0	7,8	16,5	11,8	19,1	20,0	12,5	9,0	6,6	2,8
9	-1,2	-1,9	8,4	8,1	15,2	15,2	19,6	19,6	10,6	7,5	4,0	2,4
10	2,4	-0,2	8,5	4,4	14,8	15,7	19,9	18,9	11,1	4,4	2,1	2,3
11	4,8	0,8	9,6	3,3	14,1	16,9	20,4	20,1	16,2	4,2	1,3	-0,9
12	5,3	3,1	7,6	3,5	15,3	19,0	21,0	20,0	13,2	2,8	1,6	-1,0
13	5,2	3,5	6,2	4,5	11,6	18,5	20,1	14,9	11,8	6,8	3,4	+0,6
14	1,2	3,1	4,9	4,0	17,0	18,0	20,8	12,0	13,0	9,8	5,1	+0,5
15	5,5	-1,5	6,8	9,4	10,0	21,4	22,1	16,8	15,9	5,2	2,8	-2,0
16	5,4	-3.0	6,8	9,0	16,2	19,2	20,0	20,3	17,5	9,7	2,0	-0,6
17	5.6	-6,0	2,1	6,3	18,1	14,8	18,2	19,7	19,0	8,7	2,2	+0,8
18	7,2	-0,6	1,4	5,8	18,0	13,6	17,5	17,9	10,2	8,0	6,8	-5,4
19	5,6	0,1	4,6	5,8	19,3	15,1	17,3	17,0	17,8	9,0	4,8	-12,6
20	5,1	0,5	6,4	7,0	15,1	17,9	16,0	16,8	16,6	7,2	3,5	-2,5
21	3,0	-1,2	0,1	7,4	14,1	19,4	15,6	16,2	16,5	7,9	+0,9	-0,8
22	2,7	-4,5	0,3	7,1	11,6	20,6	18,3	17,0	14,9	9,0	-0,9	+3,2
23	3,1	-4,5	2,1	9,0	8,7	20,0	18,7	18,1	13,2	10,4	-1,7	2,9
24	4,1	0,2	1,0	10,0	11,3	21,6	20,0	16,0	17,6	8,0	-3,3	2,5
25	4,3	-0,2	1,1	6,4	12,1	19,2	14,2	16,8	16,2	3,2	-7,2	1,5
26	4,4	-1,3	2,2	5,9	11,3	17,8	13,2	16,4	17,6	2,7	-7,1	0,5
27	1,7	-0,4	1,5	7,7	14,1	18,1	14,6	16,8	15,0	5,3	-2,4	4,6
28	0,8	0,0	6,6	8,8	14,8	14,5	14,6	14,7	18,5	2,8	+1,4	2,3
29	1,3		4,2	11,1	16,6	13,0	19,6	15,6	18,8	6,4	4,3	1,0
30	1,3		3,4	13,4	14,2	13,4	18,3	17,8	19,0	7,3	4,0	-1,2
31	2,0		1,1		10,6		18,5	18,4		2,4		+0,2
Monthly average	3,6	-0,7	4,6	7,2	13,9	15,6	18,3	17,6	16,4	8,2	2,7	0,9

Day	1976 I	II	III	IV	V	VI	VII	VIII
1	1,8	-7,2	4,8	10,8	7,6	10,3	18,3	13,6
2	2,0	-5,0	3,7	10,5	9,1	11,0	17,5	13,1
3	3,2	-6,8	0,7	14,8	11,8	11,4	17,3	13,6
4	-0,7	-2,0	-2,5	11,[illegible]	14,0	10,0	19,7	14,1
5	-2,1	-0,5	-4,8	10,8	13,4	12,4	18,1	13,2
6	0,7	-5,3	-3,4	10,8	13,2	13,5	14,3	13,5
7	-1,8	-5,0	-4,3	6,0	13,4	15,8	15,5	14,4
8	1,7	-6,5	-4,0	4,8	12,4	17,1	16,4	14,6
9	3,2	-4,4	1,7	4,2	15,5	14,4	15,5	14,8
10	2,8	-3,2	-3,2	4,2	16,2	11,6	13,7	15,8
11	4,3	-1,2	-3,4	4,6	15,0	13,9	16,9	15,4
12	6,5	-3,1	-2,3	6,4	15,9	14,3	19,6	16,2
13	2,5	-4,2	-0,8	7,8	14,5	16,3	20,1	15,8
14	0,0	-2,2	0,3	9,5	8,1	14,5	19,9	14,1
15	-0,9	-1,2	1,1	7,3	9,8	15,9	18,9	14,8
16	-0,0	-1,0	2,0	10,2	12,0	11,3	20,4	15,3
17	-2,1	-0,8	1,4	10,2	14,2	12,1	21,9	15,8
18	-2,3	-1,2	0,1	11,8	15,1	17,2	23,5	15,2
19	1,6	-1,0	-0,4	12,6	14,8	18,4	25,1	14,4
20	2,5	2,1	-4,8	10,6	15,2	20,2	22,7	13,9
21	2,8	1,2	-4,8	7,8	14,7	19,4	21,1	13,5
22	1,8	-0,3	-4,1	2,1	10,0	15,7	16,0	12,8
23	3,8	-2,0	-3,8	2,2	11,8	16,4	15,1	12,0
24	-0,4	-1,8	-0,7	5,7	9,5	18,4	14,7	14,0
25	-4,2	0,8	0,6	6,0	14,2	18,4	13,9	16,6
26	-5,2	4,8	4,4	6,0	16,1	17,6	17,0	17,3
27	-6,0	5,2	4,1	7,3	11,7	19,7	17,2	17,0
28	-7,4	4,0	4,7	2,3	11,8	20,8	17,6	16,4
29	-7,8	4,3	8,2	1,6	11,4	20,7	14,6	17,5
30	-7,3		8,5	3,7	13,0	18,9	16,4	18,3
31	-7,7		6,9		10,5		18,5	17,7
Monthly average	-0,7	-1,5	0,1	7,5	12,8	15,6	18,0	15,0

DISPOSAL NO. 1

THE DAILY AND MONTHLY SUMS OF PRECIPITATIONS

(in mm)

Table 6-3

Day	1 9 7 3		1 9 7 4											
	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1	.	2,0	.	.	.	.	2,8	3,5	3,4	1,2	2,2	8,7	.	6,9
2	.	.	.	.	.	.	3,4	.	.	3,0	.	5,2	4,8	4,3
3	.	0,0	.	.	.	.	0,0	11,5	0,0	0,0	13,4	0,4	0,8	1,3
4	.	1,2	.	12,1	.	.	1,2	.	.	3,9	1,1	.	0,2	1,1
5	.	0,8	.	3,3	.	.	9,1	.	.	0,4	.	.	.	3,1
6	12,6	3,4	.	.	.	.	0,0	2,4	13,5	.	1,9	.	.	0,7
7	0,0	1,7	0,0	2,3	0,0	.	3,9	3,2	0,9	.	5,2	.	.	16,1
8	0,6	7,6	1,6	.	0,1	.	.	1,5	5,5	2,2	.	3,3	.	3,5
9	0,7	2,4	.	1,1	.	.	.	1,4	3,3	16,2	.	.	.	0,9
10	.	.	.	.	.	.	.	1,6	1,2	0,7	13,2	0,1	5,7	1,4
11	.	.	3,5	.	.	.	.	3,6	6,4	0,6	.	1,3	.	.
12	.	.	0,5	.	0,2	.	.	24,9	0,2	.	.	9,6	.	.
13	0,3	.	.	0,0	.	.	.	19,1	7,9	.	13,0	0,2	.	.
14	0,8	0,5	.	.	.	.	15,6	2,1	34,0	.	.	2,5	.	.
15	0,3	1,5	8,5	.	.	.	5,0	3,9	.	.	.	12,3	.	0,4
16	.	2,5	.	.	1,0	0,0	10,2	0,0	26,5	.	.	36,2	.	.
17	.	.	4,0	.	1,0	0,0	1,6	4,0	11,3	.	.	4,7	.	0,2
18	.	0,5	4,2	.	2,4	.	.	3,5	11,6	.	0,6	0,1	.	0,7
19	.	.	7,8	8,3	.	.	.	5,5	0,6	3,8	.	.	11,7	.
20	0,0	.	7,5	1,7	.	0,3	.	1,2	2,7	13,6	16,0	3,2	.	2,3
21	.	.	0,1	.	.	1,7	8,9	0,0	3,8	0,0	3,0	29,3	.	0,1
22	.	.	.	.	.	.	6,8	0,9	.	.	0,0	.	.	.
23	2,0	.	.	.	.	.	0,1	10,3	.	0,0	.	2,4	.	.
24	2,1	.	1,9	.	.	0,0	1,0	.	12,0	.	1,7	1,9	.	.
25	.	.	1,0	0,8	.	17,2	1,0	.	6,3	.	9,7	2,6	3,5	3,0
26	.	0,5	.	0,0	.	12,9	.	5,2	.	.	0,1	4,6	.	1,7
27	0,7	.	.	.	.	1,4	0,0	27,6	.	0,9	.	5,4	1,5	6,8
28	.	.	.	.	.	0,0	0,7	1,2	.	2,3	.	.	0,2	9,1
29	3,2	.	.	.	.	.	3,7	15,4	.	.	0,2	.	3,4	5,2
30	7,4	.	0,9	.	.	.	.	0,0	.	.	7,6	.	1,7	3,6
31	.	0,7	.	.	.	.	15,7	.	.	.	.	.	.	11,2
Monthly sum	30,7	25,3	41,5	29,6	4,7	33,5	90,7	153,5	151,1	48,8	88,9	134,0	33,5	83,6

DISPOSAL NO. 1

THE DAILY AND MONTHLY SUMS OF PRECIPITATIONS
(in mm)

Table 6-4

Day	1975												1976							
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII
1	18,9	1,6	.	.	0,0	2,0	21,1	4,4	.	.	.	.	2,0	.	1,1	.	.	.	.	4,0
2	0,2	4,0	.	.	.	1,8	.	.	.	0,0	.	.	0,0	.	0,0	.	.	7,1	.	1,5
3	.	0,4	.	.	0,2	.	.	3,5	.	0,6	0,4	.	1,9	.	0,0	.	.	.	.	8,0
4	2,9	.	.	.	0,0	0,0	.	.	.	.	.	0,7	.	.	0,1	.	.	.	.	0,1
5	1,7	.	3,9	3,0	.	0,0	.	5,8	5,7	7,3	.	0,3	0,2	.	0,4	.	.	.	.	2,4
6	1,2	.	0,6	.	.	.	.	.	0,0	.	.	3,8	.	.	0,3	.	.	.	.	2,2
7	0,0	0,2	.	12,6	.	5,6	.	.	.	5,3	1,1	0,1	.	.	0,5	.	.	.	3,8	12,3
8	1,2	0,2	.	.	.	9,8	.	.	.	2,8	.	.	.	.	.	5,6	.	.	.	0,3
9	.	.	.	.	1,8	2,1	.	.	.	2,2	.	.	4.2	.	0,0	.	.	.	15,1	.
10	.	.	0,0	12,5	.	.	2,1	3,8	.	0,0	.	1,0	11,5	0,1	0,1	.	.	.	2,2	.
11	.	.	0,2	.	.	.	.	.	.	.	0,0	.	2,1	2,8	.	.	.	.	.	1,2
12	.	.	3,9	.	.	.	.	0,9	12,0	1,5	.	.	9,9	0,4	.	.	.	.	19,1	.
13	0,5	1,7	8,9	0,0	.	3,5	.	.	.	3,0	0,5	.	2,6	0,0	.	.	21,5	7,8	.	.
14	.	0,6	9,0	7,1	.	.	.	.	.	28,2	20,1	0,0	15,1	.	.	2,0	17,0	.	.	0,3
15	.	.	.	6,6	.	.	.	.	.	9,7	2,0	0,0	0,3	1,2	.	0,0	0,1	14,6	1,6	.
16	.	1,5	0,8	9,3	.	7,1	.	0,9	.	3,1	.	0,1	0,2	.	.	2,9	.	2,4	.	.
17	.	.	7,8	0,2	0,0	0,0	.	1,3	.	0,8	.	10,5	0,9	.	1,6	.	.	8,3	.	.
18	.	0,0	0,3	.	.	6,1	0,1	27,4	.	29,2	19,5	0,0	4,9	.	2,7	.	.	.	.	1,3
19	0,1	14,2	1,1	.	2,5	0,0	6,0	0,1	.	6,0	1,4	.	.	.	8,8	.	.	.	.	2,6
20	.	.	.	.	.	58,4	45,4	.	.	6,3	2,6	1,0	.	.	1,2	.	1,9	.	.	2,3
21	.	.	.	.	.	4,2	2,5	.	.	11,3	3,4	.	1,1	.	1,6	0,1	34,6	.	28,8	.
22	.	.	.	.	.	0,0	.	.	.	.	1,0	.	4,0	.	.	2,0	15,9	.	15,0	.
23	0,0	.	.	.	0,0	52,2	.	.	.	.	.	.	2,5	0,2	.	0,0	.	.	39,3	.
24	.	.	.	6,5	.	18,8	27,0	.	.	0,0	.	.	0,6	.	.	4,2	0,0	.	5,2	.
25	.	.	0,5	0,5	24,2	0,3	17,5	24,6	.	0,2	0,0	1,5	0,1	.	0,0	2,7	.	.	2,2	.
26	.	.	3,7	1,5	2,2	.	2,5	10,1	2,3	0,5	.	10,1	0,0	0,3	8,1	2,9	17,2	.	0,3	.
27	.	.	.	.	.	.	3,1	.	.	.	.	2,3	0,0	0,1	3,6	.	2,5	.	.	.
28	1,7	.	3,1	.	.	32,5	1,6	.	.	0,1	.	.	.	.	0,0	0,0	2,7	.	.	.
29	1,3	.	.	.	2,8	.	.	3,4	.	.	.	.	0,1	.	.	.	.	.	.	.
30	0,7	.	10,8	.	5,8	6,6	0,6	1,1	.	.	.	.	.	.	0,1	.	.	.	.	.
31	.	.	3,7	.	5,6	.	16,7	.	.	.	.	.	.	.	.	.	28,2	.	3,9	1,2
Monthly sum	30,4	24,4	58,3	59,8	45,1	211,0	146,2	87,3	20,0	118,1	52,0	31,4	64,2	5,1	30,2	22,4	141,6	40,2	136,5	39,7

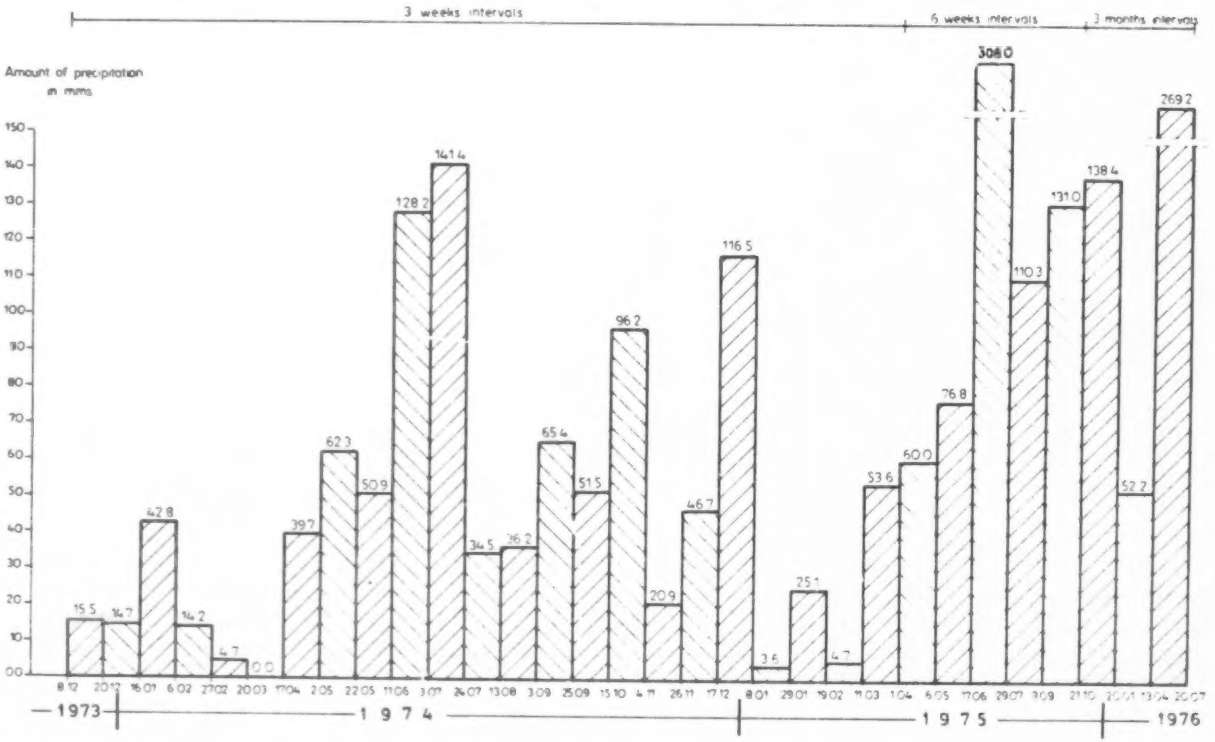

Fig. 7 DISPOSAL № 1. THE DIAGRAM OF AMOUNTS OF PRECIPITATION FOR SAMPLING TIME INTERVALS

small anomalies become pronounced due to deleveling of the roof of the bottom clay surface, which in elevation causes a phenomenon of a certain small swelling of the ground water.

The hydraulic gradients in the disposal's subsoil and in its immediate neighbourhood are variable within limits of I max = 0,04 to I min = 0,002, and the velocities of ground water flow are within limits V max = 1,2 m/day to V min = 0,1 m/day. The most often happening velocities are of a rank V aver. = 0,5 m/day.

The described above aquifer is supplied mainly by precipitation, therefore this is factor affecting the position of the water table, so the conditions of the disposal waterlogging are climatic, especially the amounts of precipitation.

Average daily air temperatures in an observation station 12 km away from the experimental disposal for the period from Nov. 1, 1973 to June 30, 1975 are specified on the table no. 6-1 and 6-2.

These values of temperatures are provided here also to, help for comparisons with similar objects in the U.S.A. This can have a significance in estimating the value of evaporation coefficient as required for the estimation of amounts of rain water leaching into the disposal, and which may percolate to contact the ground waters. In relation to the long term averages for this region of Poland the abnormally warm winters of 1973/ 74 and 1974/75 are emphasized.

The sums of daily precipitations recorded in an observation station situated close to the disposal (2 km) illustrates the table no. 6 - 3 and 4.

As from the above table appears, and also from the comparisons with long term averages, certain observations could be made:

i) a highest daily precipitation was 58,4 mm
ii) a highest monthly precipitation was 211,0 mm
iii) a lowest monthly precipitation was 4,7 mm.

Phenomena of these large discrepancies in the sums of precipitation have an essential significance, as are finding a pronounced reflection both in the position of the ground water table and in the degree of pollution by the disposal, which will be discussed in further chapters.

For the considered region of Poland and for conditions of a lacking surface run-off (so was shaped disposal) and no vegetation cover on the disposal it was determined that:

- the daily amount of an underground run - off may fluctuate within limits of 0,6 to 0,8
- annual amount of underground run-off may fluctuate within the 0,4 to 0,6 limits.

ANALYSIS OF DISPOSAL FORMATION, AND THE DISPOSED MATERIAL

The described terrain for the disposal was prepared levelling the floor on the selected area and lowering it a little. The sand was heaped to form banks 1.5 do 1.8 m high. Formed in this way was a bowl 42 m long, 2.1 m wide and from 1.5 to 2.2 m deep. In this bowl during a 10 days time, on turning October to November 1973, stored was about 1500 m^3 of waste material consisted of:

- about 500 m^3 of fly ash (400 m^3) and slags (100 m^3) from power plants fired with bituminous coal,
- about 1000 m^3 of sterile rock and a waste coming from dry separation (about 200 m^3) and from coal washeries (about 800 m^3).

Analysing the dimensional distribution of material of the disposal, one can say that in the eastern and the central part of the disposal prevailing element are the coal refuse (gob), and in the western part the ashes from the power plant (Fig. no. 4).

The bottom of the disposal is situated just above the ground water table, and during periods of elevated water table the bottom parts of the disposal may periodically be immersed to a few centimeters depth.

Going over to the qualitative description of the disposed waste material one has to emphasize, that this material has no uniform character and each type of it requires a separate characterization.

The waste material from the power plant

This is composed of fly ashes (ab. 80 % mass) and slags (ab. 20 % mass). The fly ash is characterized by the following average basic components:

losses of roasting	5,42 %
$SiO_2 + R$	74,10 %
CaO	3,11 %
MgO	1,20 %
SO_3	0,67 %
Fe_2O_3	8,22 %
Al_2O_3	3,61 %
K_2O	2,80 %
Na_2O	0,87 %

Granulometric composition:

fraction greater than 0,5 mm - 1,6 %
fraction 0,5 - 0,25 mm - 9,3 %
fraction 0,25 - 0,10 mm - 25,4 %
fraction 0,10 - 0,06 mm - 14,7 %
fraction below 0,06 mm - 49,0 %
specific gravity - 2,24 G/cm^3
bulk density - 0,89 G/cm^3

Slag is characterized by the following average basic components:

losses of roasting - 7,09 %

SiO_2 + R - 69,79 %

CaO - 2,37 %

MgO - 1,23 %

SO_3 - 1,42 %

Fe_2O_3 - 8,68 %

Al_2O_3 - 6,01 %

K_2O - 2,60 %

Na_2O - 0,81 %

Granulometric composition:

fraction above 2 mm - 19,1 %
" 2,0 - 1,5 mm - 2,6 %
" 1,5 - 1,0 mm - 8,45 %
" 1,0 - 0,5 mm - 13,45 %
" 0,5 - 0,1 mm - 52,1 %
" 0,1 - 0,06 mm - 3,1 %
" below 0,06 mm - 1,2 %
bulk density - 0,68 G/cm^3

The above parameters were obtained from four rendered average samples, each one was collected from the power plant during a time period of 7 - 15 days, 1 kg daily, and then weighted average. All parameters were determined according to the actually obligatory Polish Standards.

Knowing the physico-chemical character of the waste material subsequent investigations were made, the object of which was to determine the quantity and quality of ions passing into water dependent on the time of contact of slags and ashes with water. A test was made for each distilled water in volumetric proportion of 1:1, whereby the time of contact was varied within limits of 1 - 20 hours.

Each series was composed of five samples. In all laboratory tests the same procedure was used; measuring was 2 dm^3 of veighted average waste material, placed in a glass container and mixed with

2 dm^3 of distilled water, and after mixing left for a time length of 1 hr., 2 hrs., 5 hrs., 24 hrs. and 120 hrs. (table no. 6 - 5).

After a lapse of time from the moment of contact the slag or ash with water content was mixed and the water sample strained for chemical analysis (table no. 6 - 6).

Similar tests were carried for the mixture of four lots of ashes (in proportion 1:1) and admixture of slags, using in tests 10 dm^3 of waste material mixture and 10 dm^3 of distilled water.

The filtrates were submitted to chemical analyses similar to the water analyses. The results are shown on the tables on next pages.

From the above investigations it appears, that the fastest leaching of components was during the first hour of contact of ash with water. As the process continued this was slower, whereby the quantity of leached out ions during the 5 days period constituted on average 0,38 % of the ash mass.

Comparing the rate of leachate in a determined time, ions of slag and ash in analogical conditions indicates, that despite similar compositions three times more ions of ash passed into water than of slag, and a greater rate of leaching is observed during the first hour of contact with water. This can be explained by a smaller, size of ash particles and the greater surface of contact with water.

During the first hours of ash contact with water (especially after 5 hours), greater, in case of slag, chemical interaction of ions was observed.

Maximum value of specific conductivity and of dry residue of the water extract was occurring after 2-5 hours contact of ash with water. Water solutions were indicating a strongly alkaline reaction from 9,6 to 12,8 pH values, whereby the maximum pH values occurred mainly after the 2-5 hours' time length of the ash contact with water. In water solutions after breaking off the contact of ash with water after

CHEMICAL ANALYSES OF WATERS AFTER STATIONARY CONTACT BETWEEN ASH AND DISTILLED WATER AT A VOLUMINAL RATIO 1:1

Table no. 6-5

Time of contact in hs	pH	Conductivity us/cm	TDS mg/l	Ca^{+2} mg/l	Mg^{+2} mg/l	Al^{+3} mg/l	SO_4^{-2} mg/l	Cl^- mg/l	OH^- mval/l	CO_3^{-2} mval/l	HCO_3^- mval/l	Na^+ mg/l	K^+ mg/l
I run													
1	8,0	3200	-	542,7	38,42	257,0	1010,1	10,6	0,0	0,24	0,0	162,1	428,0
24	8,8	5400	-	498,0	33,00	359,6	1234,6	38,99	0,0	0,8	0,4	-	-
II run													
1	12,6	4750	2930,0	628,0	36,3	307,8	1266,7	25,4	14,0	0,0	2,0	85,8	106,4
2	12,7	5380	3346,0	708,0	24,2	513,4	1453,4	31,9	19,4	0,0	1,6	-	-
5	12,8	5390	3030,0	662,0	38,7	454,4	633,9	30,0	21,5	0,0	1,0	71,9	90,9
24	10,4	2142	1802,0	384,8	19,4	302,6	949,6	33,0	10,4	0,0	3,2	-	-
120	10,2	2010	1848,0	288,6	14,6	284,1	1088,96	32,3	3,0	0,0	2,8	-	-
III run													
1	12,0	3980	2622,0	657,3	2,4	135,7	1038,9	9,23	34,1	0,0	3,2	-	-
2	11,3	3843	2090,0	513,0	14,6	152,6	404,7	8,5	29,2	0,0	4,0	-	-
5	11,1	4041	2302,0	585,2	24,5	337,1	902,0	4,9	28,8	0,0	4,8	58,2	60,8
24	11,1	4261	2358,0	609,2	4,9	41,5	840,9	9,9	35,0	0,0	1,4	-	-
120	10,7	1912	1118,0	344	1,2	145,2	447,7	18,4	0,0	6,3	0,8	99,3	141,61
IV run													
1	11,6	3613	2720,0	633,3	1,2	527,3	1263,2	34,1	20,4	0,0	3,8	-	-
2	11,7	3484	2434,0	937,9	4,9	466,4	1123,0	32,0	20,8	0,0	3,0	89,8	82,1
5	11,6	3469	2536,0	653,3	0,0	546,9	1252,9	33,4	17,5	0,0	3,4	-	-
24	11,8	2861	2620,0	573,2	2,4	495,5	1171,8	35,5	25,4	0,0	2,2	-	-
120	11,1	2442	1334,0	252,5	2,4	135,7	779,0	42,6	6,6	0,0	2,8	-	-
Combined run													
1	9,6	2936	2874,0	517,03	28,0	524,2	1714,6	9,2	1,2	0,0	1,8	-	-
2	9,9	3074	3046,0	[illegible]	26,8	444,7	1841,7	14,2	0,6	0,0	2,6	-	-
5	9,9	3379	3174,0	573,1	7,3	599,9	1840,9	15,6	0,6	0,0	2,8	-	-
24	10,8	3547	3372,0	567,1	2,4	392,3	2000,4	28,4	2,4	0,0	1,4	-	-
120	10,8	3579	3324,0	478,9	2,4	41,9	1937,7	-	2,4	0,0	2,0	210,8	434,1

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CHEMICAL ANALYSES OF WATERS AFTER STATIONARY CONTACT BETWEEN SLAG AND DISTILED WATER AT VOLUMINAL RATIO 1:1

Table no. 6-6

Time of contact in hs	pH	Conductivity us/cm	TDS mg/l	Ca^{+2} mg/l	Mg^{+2} mg/l	Al^{+3} mg/l	SO_4^{-2} mg/l	Cl^- mg/l	OH^- mval/l	CO_3^{-2} mval/l	HCO_3^- mval/l	Na^+ mg/l	K^+ mg/l
I run													
1	8,5	1344,0	1436,0	279,8	27,8	98,9	822,0	28,4	0,0	0,4	0,4	66,1	102,8
24	9,8	1689,0	1322,0	320,4	7,3	284,1	1036,7	38,9	0,0	0,2	0,2	-	-
II run													
1	9,7	792,0	732	128,0	60,5	114,4	854,0	35,4	0,1	0,4	0,0	-	-
2	9,2	948	778,0	50,1	52,3	160,6	469,5	40,5	0,0	0,8	1,8	-	-
5	9,0	568,0	-	42,0	6,1	traces	285,5	24,8	0,0	0,8	1,5	17,1	16,8
24	9,9	784,0	650	116,0	4,8	100,5	798,0	3,34	0,0	0,2	0,4	-	-
120	10,1	692,1	987,0	180,0	0,0	116,1	486,0	7,0	0,4	0,0	0,6	-	-
III run													
1	8,6	645,0	1030,0	76,3	51,6	32,8	275,0	38,3	0,0	0,4	0,2	-	-
2	8,8	685,0	610,0	67,8	28,7	38,2	323,0	45,5	0,0	0,2	0,5	32,0	29,6
3	8,9	929,0	682,0	90,2	45,0	173,3	424,8	51,8	0,0	0,4	1,3	-	-
24	9,3	971,0	809,0	92,2	41,4	0,0	398,9	51,1	0,0	2,2	0,4	-	-
120	9,45	800	714,0	202,0	30,8	85,9	358,3	52,7	0,0	0,4	0,6	35,6	32,12
IV run													
1	9,1	834,0	522,0	112,2	-	133,0	335,8	33,4	0,0	0,2	1,2	-	-
2	9,1	427,0	316,0	52,1	7,3	76,4	164,8	17,5	0,0	0,4	1,1	-	-
5	9,7	1003	714,0	132,3	8,5	38,7	427,7	44,02	0,0	0,8	0,8	49,5	33,5
24	9,9	939,0	784,0	140,28	9,7	150,5	449,4	54,7	0,0	1,6	0,4	-	-
120	10,1	1005	716,0	156,3	3,6	48,8	379,7	47,6	0,3	2,0	-	-	-
Combined run													
1	8,8	704	542,0	56,1	31,6	4,8	305,0	24,9	0,0	0,2	1,1	-	-
2	9,2	700	534,0	56,1	34,0	5,8	287,0	24,9	0,0	0,4	1,0	-	-
5	8,9	800	527,0	60,1	27,7	9,0	314,9	31,9	0,0	0,2	1,3	-	-
24	9,3	881	600,0	72,2	47,7	1,6	350,0	34,8	0,0	0,6	1,3	-	-
120	9,4	992	822,0	92,2	49,9	120,8	416,1	36,9	0,0	1,4	1,7	31,0	32,8

7 days one observed a decrease in the pH down to about 8 pH value and a further precipitation of white sediments of chiefly carbonates.

The intensity of leaching particular ions during the time of a 5 - hour contact of ash with water was very different. Most intensely leached was sulphate ion from both ash and slag alike, in a quantity of 10-20 % of the entire SO_4 content in ash. Then the calcium ion in quantity of 5 %, aluminium ion in quantity 0,85 - 4,7 %, and potassium ion in quantity 2,1 %. Magnesium and sodium were leached in small quantities each about 0,4 % of total quantity. This was caused probably by a high pH, inducing precipitation of the magnesium ions in a shape of magnesium hydroxide, a reaction which begins by the 9,4 pH value. No iron ions passing into water solution were observed, despite their considerable content in ash (also owing to high alkalinity of the solution, which may effect precipitation of the iron hydroxides).

Coefficients of K_x migration for particular ions after 5 hours time computed according to the formula (4 - 26) and also the migration intensity are shown on the table below:

Type of ion	Coefficient of K_x migration	Intensity of element migration
Ca^{2+}	9,2 - 17,3	easily mobilized
Al^{3+}	3,5 - 7,7	" "
Mg^{2+}	0,9 - 2,0	mobile
Na^{2+}	3,9 - 5,7	easily mobilized
K^{2+}	1,4 - 1,8	mobile
SO_4^{2-}	30 - 60	very mobile

Gob are composed of sterile rock separated from the winning by way of dry separation (20 %), and of wastes from the coal washeris, (80 %) whereby these differ mainly in the content of organic matter.

Sample of rock coming from a dry separation had shown the following per cent chemical composition of the basic components:

Content of the component in percents						
Roasting losses	SiO_2	CaO	MgO	SO_3	Fe_2O_3	Al_2O_3
20,94	50,35	2,80	2,40	1,40	5,14	16,72

On the other hand the sample of washed wastes contains the following % chemical composition of the basic components:

Content of the component in percents						
Roasting losses	SiO_2	CaO	MgO	SO_3	Fe_2O_3	Al_2O_3
28,05	40,69	1,14	0,32	1,30	3,99	24,47

Without any systematic experience regarding the method of how the laboratory tests of washed wastes were to be performed, gob were subjected to somewhat different tests to tests of ashes and slags. Five samples of dry, separated dry and five samples of rock separated from the mass of winning from a coal washer were taken. These samples were subjected to washing in a water environment for 24 hours, the time was not varied as was the case of ash and slag. However, one composed sample was subjected to a contact with water for the time period of 15 days. The acquired results are illustrated on the following table:

Results of laboratory gob leachates analyses

Table 6-7

Designation	Units	dry wastes after 24 hrs, mg/l		washed wastes, after 24 hrs. mg/l		test of composed compounds mg/l
		from - to	average	from - to	average	after 15 days
Turbidity	mg/l	1870 - 10 000	4 748	3 120 - 17 500	9 124	-
Colour	mg/l	20 - 400	144	5 - 2 500	603	-
Conductivity	us/cm	606 - 2 412	1 409	790 - 2 883	1 528	3 970
Diss. substances	mg/l	402 - 1 531	960	675 - 1 768	1 021	2 450
Diss. miner. subst.	mg/l	353 - 1 302	809	581 - 1 737	908	2 360
BOD 5	mg/l	21 - 110	53,7	35 - 132	68,7	15,0
pH	-	7,9 - 8,5	8,2	7,0 - 8,4	7,8	8,1
Hardness	german grades	0,7 - 3,7	1,76	1,2 - 4,8	2,64	3,10
Sulphates	mg/l	74,5 - 243,5	121,1	82,7 - 393,1	201,1	350
Chlorides	mg/l	55,4 - 670,1	310,8	108,9 - 661,0	304,9	520
Sodium	mg/l	92,0 - 449,0	258,2	145,0 - 575,0	291,8	595
Potassium	mg/l	29,0 - 32,0	29,7	10,0 - 35,0	24,8	36,5
Calcium	mg/l	4,4 - 20,0	10,0	7,2 - 24,4	14,3	45,0
Magnesium	mg/l	0,5 - 3,9	1,61	0,5 - 6,8	2,9	17,0
Total iron	mg/l	3,5 - 37,7	13,6	6,0 - 25,6	17,2	26,5
Ammonia	mg/l	2,2 - 16,1	10,5	1,4 - 14,9	8,0	3,3
Nitrites	mg/l	0,1 - 2,3	1,0	6,2 - 3,0	1,74	2,16
Nitrates	mg/l	0,3 - 8,0	4,7	1,3 - 3,5	2,36	5,62
Manganese	mg/l	traces - 0,4	-	traces - 4,0	-	0,7
Phosphates	mg/l	0,06 - 0,6	-	traces	-	0,64
Phenols	lack	lack	-	lack	-	lack

Notice: From different tests was obtained, that similar waste material may give in optimum conditions even 2-fold greater concentrations of the series presented on this table.

As the above specification appears the general quantitative potential of pollutions of gob in summation is similar to that of ashes and slags. However a clear qualitative change can be observed. The dominating leached compounds in gob are chlorides with concentrations 500 mg/l, while in the case of ashes these did not exceed 50 mg/l. A lesser role is played by sulphates, the concentrations of which reach maximally the 350 mg/l, white in case of ashes these exceed even 1000 mg/l.

Among the cations, sodium is being leached in significant quantites to nearly 600 mg/l value, while in much smaller amounts as compared with ashes are leached calcium (to 50 mg/l), potassium (to 36,5 mg/l) and magnesium (to 17 mg/l). Reaction pH is close to neutral, and on average is coming pH 8.

Attention is draw to the fact that the concentration of pollutants grows after a longer time of contact with water - the sample after 15 days gave a 2-3 times greater concentration than after 24 hours. This is particularly apparent in comparison with ashes where the phenomenon of passing into solution is much faster.

Independent of the above tests a comparison test was made in a manner similar as in the case with ashes, i.e. the collected sample was subjected to contact with distilled water in proportions 1:1. Following this an analysis of filtrate was made after the sample contact with water of 1 hr, 24 hr, and 144 hours, the obtained results are specified on the table below:

Designation	Units	Time of contact with water of waste material in hours		
		1	24	144
pH	-	7,7	7,2	6,9
Conductivity	µs/cm	3700	461,0	856,0
Total diss. subst.	mg/l	218,0	292,0	490,0
Sulphates	"	19,01	98,06	221,4
Chlorides	"	41,15	61,77	106,35
Calcium	"	6,01	16,00	34,00
Magnesium	"	0	1,09	3,60

Continuation table

Designation	Units	Time of contact with water of waste material in hours		
		1	24	144
Aluminium	mg/l	0	0,23	0,40
Sodium	"	17,63	68,20	143,20
Potassium	"	9,15	13,65	23,06

The object of this investigation was also to gain more methodical experiences, how to conduct in the future the tests of the waste material in laboratory conditions, in order to obtain the most adequate results in relation to actual field conditions.

Porosity of the waste material stored with no greater segregation, (made to retain the possibly closest natural conditions of the wastes storage; planned in the future is a joint storage of this material), comes to 30 to 35 %, on average to about 32,5 %.

More complicated however is the issue of determining the coefficient of the deposited material. Owing to a great range of the granulation values (from dusty fraction, which represent ashes and washed slurry, to stone fraction represented by waste matter coming from dry and washer segregation) difficult is to speak about any average values. The situation complicates also the lack of the material segregation and the resulting from it great variability in permeability both in perpendicular and in horizon.

An element additionally complicating the issue is the time variation resulting from washing by the filtrating waters the finest fractions of the material mass and their sedimentation in the bottom parts of the disposal; also natural compaction of this disposal is a further handicap.

It appears however, that one can operate with values attributed to particular types of the waste material, and so the coefficient of ash filtration fluctuates within limits of k = 0,1 to 0,3 m/day, and of gob k = 5-200 m/day, (excluding the washed slurries).

MONITORING SYSTEM

In the above considered hydrogeological conditions for the inspection of the above discussed disposal influence on the ground waters within its neighbourhood, a system of 12 monitoring wells was installed (fig. 3,4).

Two wells were made on the disposal itself, with the object to have inspection regarding its influence on the ground waters flowing in its direct subsoil (wells 11, 12).

Five successive wells were made around the disposal at distances of 3 to 5 m (wells no. 1,2,8,9 and 10) from its boundary.

Four further wells were localized at distances 15 m (two wells) 35 m, and 75 m from the disposal in directions where was expected, its influence (wells nos. 3,4,6 and 7).

One well was localized behind the ditch conducting water, on an area where the influence of the disposal should not appear (well no.5).

The wells were drilled with dry method, with diameters 8" and then columns of pipes were installed with 4" diameters. These columns consisted of:

- pipe below the filtrating section, with solid wall, 1 m long, fulfilling a role of sedimentation tank
- filter proper, a section of perforated pipe wrapped round with nylon gauze, outside which a packing of washed granulated gravel was made
- section of pipe above the filter part, with solid wall protruding above the terrain surface, fitted on top with a tight cover protecting against atmospheric influence and access of outside persons.

The basic lengths of particular wells are shown on the table below.

No. of well	Characterization of the lining		
	Section above filter (m)	Filter proper m.	Section below filter
P-1	0,70	1,40	1,00
P-2	0,70	1,30	1,00
P-3	0,70	1,60	1,00
P-4	0,70	0,90	1,00
P-5	0,70	1,60	1,00
P-6	0,70	0,80	1,00
P-7	0,70	0,50	1,00
P-8	0,70	1,50	1,00
P-9	0,70	0,70	1,00
P-10	0,50	0,30	1,00
P-11	3,20	1,40	1,00
P-12	3,20	0,60	1,00

WATER SAMPLING AND FIELD MEASUREMENTS

On the described disposal systematic observations and tests commenced on the 8-th of December 1973, which comprised:

- the measurement of the water table position in all wells with accuracy of ± 1 cm
- water sampling for physico-chemical analyses.

The above scope of tests was performed in 3-weekly cycles (with departures of ± 1 day), for the time period of 15 months, i.e. to the 1-st April 1975, then for period of following 6 months in 6-weekly cycles, and later on in 3 months. The water sampling was carried out in the following way. Before the sampling, pumping out of water was made for a short period. The quantity of pumped out water was determined separately for each well dependent on its depth. As a rule adopted was the requirement to pump out a quantity of water corresponding to double volume of the well. The motivation of this procedure was on one hand the purposefulness of a prior removal from a well of water, that could be for long time in contact with the air and with the pipes, and on the other hand the intention was not to disturb the natural regime of the ground waters, which might occur when pumping out too much water. Then a sample of water was taken. Parallel with sampling waters from wells, an inspection water sample was collected from the pit under the foot of slope 30 m above the disposal (upstream of ground waters) with the object to have a record of the initial composition of water entering into contact with the disposal.

Certain deviations from the above scheme took place, which were:

- a few times during the initial time period no water samples were taken from wells P-1, P-2, P-9 and P-11, due to their clogging, which subsequently was removed

- from the well P-11 starting from the 25-th of January of 1975 two water samples were being taken each time (the sample marked in tables no. 11 was taken in the same way as the samples from all other observation wells, while the sample marked no. 11/2 was taken from this well without previous pumping); this individual treatment of the well P-11 is due to the fact, that this well is localized on the disposal itself and was showing in 1974 an incomprehensibly small pollution rate of waters; it was important to obtain an inspection sample, and to acquire a material to derive more general methodical conclusions regarding the effect of pumping the wells on the obtention of the most proper sample

- sampling of the well no. 5 was abandoned because it showed the influence of different factors.

This comparison had shown, that pumping of a well before sampling for analyses had no effect whatever on the results. (Compare results of samples 11 and 11/2 on the tables enclosed) to the full edition.

For shortened analyses the water was being collected into polyethylene containers in quantity 5 liters from each well.

For the full analyses waters were being taken in quantities:

- 5 liters to the polyethylene containers
- 1 liter to glass container for the determination of phenols, this sample was being stabilized immediately with phosphoric acid and with copper sulphate
- 1 liter to a polyethylene container to determine the cyanides where the sample was immediately stabilized with addition of KOH granules.

In this way collected samples were delivered to the laboratory within 3 to 5 hours.

After delivery to the laboratory the sample was subjected immediately to a vigorous stirring in a mixer, then filtrated and duly divided and acidified.

We abandoned an immediate acidification in the field owing to consideration that:

- to deliver the samples to the laboratory takes only few hours
- it is appropriate to perform analyses on a large rendered average sample, and not on small, separate samples
- from the point of view of the investigated phenomenon more essential were the dissolved substances, then the suspended matter, which in the course of filtration through a porous medium is being sedimented on the grains of the soil (the methodology of research in this aspect would be somewhat different of course if the flow of polluted waters was to pass through a medium with fissures).

The described procedure was in agreement with the Polish Standards relevant to water sampling from wells used for consumption purposes.

METHODOLOGY OF LABORATORY TESTS

The filtrated samples prepared in a manner described above were subjected to analyses, employing the following analytic methods:

- color - through comparison with a dichromate - cobaltic pattern scale
- smell - organoleptically, cold, according to 5 - grade scale of smell intensity adopting symbol R - for the group of vegetative smells, G - for putrescible, and S - for specific smells
- conductivity - by means of conductometer
- pH - with potentiometric method
- total hardness - through titration with the EDTA reagent
- basicity - through titration with hydrochloric acid against the methyl orange
- acidity - in titration with sodium hydroxide gainst phenolphtalein
- instant oxygen consumption - through titration, cold, with permanganate of potash
- oxygen consumption - through determination of the potash permanganate consumption by a sample during a heating in water bath for 20 minutes
- total dissolved substances - through the determination of a residue after evaporation of a filtrated sample, and drying it in temperature 105°C to constant weight
- dissolved mineral substances - determined through roasting the dry residue of filtrated sample in temperature 600°C
- dissolved volatile substances - calculated from a difference between the dissolved total and mineral substances
- chlorides - with Volhard method in titration with silver nitrite
- sulphates - with nephelometric method by means of autoanalyser

- nitrates - with colorimetric method with the help of autoanalyser after a redutcion to nitrites with hydroxylamine solution
- ammonia nitrogen - distillation method with the Nessler reagent
- albumin nitrogen - distillation method with Nessler reagent, after alkaline decomposition in the potash permanganate solution
- phosphates - colorimetric method in reaction with ammonium molybdate and a reduction to molybdate blue
- free cyanides - extraction colorimetric method after distilling sample acidified with tartaric acid, brominating and reaction with bentidine - pyridine reagent
- phenols - monohydric phenols were determined after distilling the sample, with colorimetric method in aminoantipyrine
- bivalent iron - colorimetric method in reaction with 1,10 - phenanthroline
- summary iron - colorimetric method with 1,10 - phenanthroline after reduction of trivalent iron
- trivalent iron - calculated from difference of the two above determinations
- calcium, sodium, potassium - with the method of flame photometry
- copper, zinc, lead, magnesium, manganese, strontium, cadmium - with method of atomic absorption
- aluminium - colorimetric method with aluminon
- chromium - colorimetric method with diphenylcarbazide
- arsenic - molybdate colorimetric method after educing arsenous hydride from saple and oxidising with sodium hypobromite to As^{5+},
- mercury - after reduction to elementary mercury determined with colorimetric method in reaction with iodine and copper salts

- silica - dissolved reactive silica was determined with ammonium molybdate

- $B.O.D_5$ - biochemical oxygen demand was determined in analyses of samples for the oxygen content with the Winkler method before and after the 5-day incubation period in temp. 20°C

- molybdenum - with colorimetric thiocyanate method

- boron - colorimetric method in reaction with bianthrimide in an environment of concentrated sulphuric acid.

During the first 8 months of tests the determination of heavy metals was carried out with an accuracy equal to the maximum admissible contents of these elements in accordance with Polish Standards for drinking water. Afterwards with maximal accuracy permitted by the above mentioned methods.

RESULTS AND DISCUSSION OF HYDROCHEMICAL TESTS

The results acquired from tests are specified on tables, the complete set of which is avaiable in Project Officer's and Author's office shown on the enclosed diagrams (fig. no. 8 to fig. no. 23) exhibiting synthetically the course of the phenomenon. Shown on the tables are all results of analyses for all samples, collected from all monitoring wells. For a better readability of the enclosed diagrams the results of groups of wells with similar disposition in regard of their position to, and distance from the disposal were assembled in sections.

The following zones were assigned:

- the direct subsoil of the disposal (represented by well no. P-12) - zone B

- toward the direction of the main down stream of the ground water flow (wells no. 8 and 9) - zone C

- intermediate zone between the main direction of ground water flow and the direction of smaller dip of the water table (well no. 2) - zone D
- zone of much smaller dipping of the ground water table localized at increasing distance from the disposal (wells nos. 1,3,4,6,7) - zone E
- initial water zone not being in contact with the disposal - zone A.

Results of wells not taken into account were:

Well no. 5 -	after the initial period of observations was considered this well underwent different disposal influences and this made the obtained results questionable, and no samples were taken from it for this reason
Well no. 10 -	similar reasons as with well no. 5
Well no. 11 -	for reasons not accunted for so far, this well supplied results inconsistent with results from other wells; however very interesting observations were made of this well regarding the methodology of sampling (discussed previously, and the results of sample analyses from this well are enclosed on the tables).

Passing over to a substantial discussion of results of the above parameters, one may state the following:

The weight by volume of initial water was 0,9975 G/cm^3 - in direct subsoil of the disposal (zone B) this was 0,9983 to 0,9986 G/cm^3, in the down stream course of ground waters (zone C) 0,9985 to 0,9995 G/cm^3; in intermediate zone D 0,9977 to 0,9979 G/cm^3 and in the direction of the small dip of ground water table (zone E) was 0,9975 to 0,9980 G/cm^3.

As the above data appears, there exists a noticeable difference between the weight by volume of waters polluted and waters which did not get into contact with the disposal. Weight by volume of waters polluted is greater from the volume weight of pure waters by maximally 0,002 G/cm^3, i.e. in approximation 0,2 %.

pH reaction (Fig. no. 8) - during the period of commenced observations (i.e. after the storage of waste material) the pH reaction increased in subsoil under the disposal; this occurrence was showing its greatest values observed in the well no. 12 (maximum pH = 8,5 was noted on the Feb. 6, 1974) and the increased pH value under this disposal in relation to initial water (by about 0,4) persisted for about half a year, later on this difference gradually smoothed itself out; in other wells, although the pH was greater by about 0.2 in comparison to initial water, it seems however that this was not due to the influence of the disposal. It is belived that the disposal did not contribute materially to the change in the pH of ground waters.

Conductivity (Fig.no.9) - the conductivity of initial water during the principal period of observation, i.e. from the Jan.1,1974 to May 6,1975 fluctuated within very small limits of 200 - 300 µS/cm. From the May 6, 1975 on it increased rapidly to 2000 - 3000 µS/cm, effecting pollution of the entire aquifer by outside factors, and in connection with it the time period after this could not be considered to be of reference value. The maximum value acquired in laboratory tests amounted to 5000µS/cm. After the storage of waste material we observed immediately and for the period of 6 months a clear increase in conductivity of the ground waters in the zone B, from values of a 500 µS/cm rank during the first month to a rank value of 1200 µS/cm in the 7-th month. After 8 months this quantity dropped a little, and afterwards oscillated within limits of 400 - 800µS/cm. With the delay of about 6 months the conductivity increased in the zone C in ground waters flowing from under the disposal. During the period of June and July 1974 it grew from about 300 µS/cm to over 2000 µS/cm, and then fell a little (to about 1500 µS/cm), and again increased to a value of the 2000-3000 µS/cm rank. In the zone D the increase in conductivity was

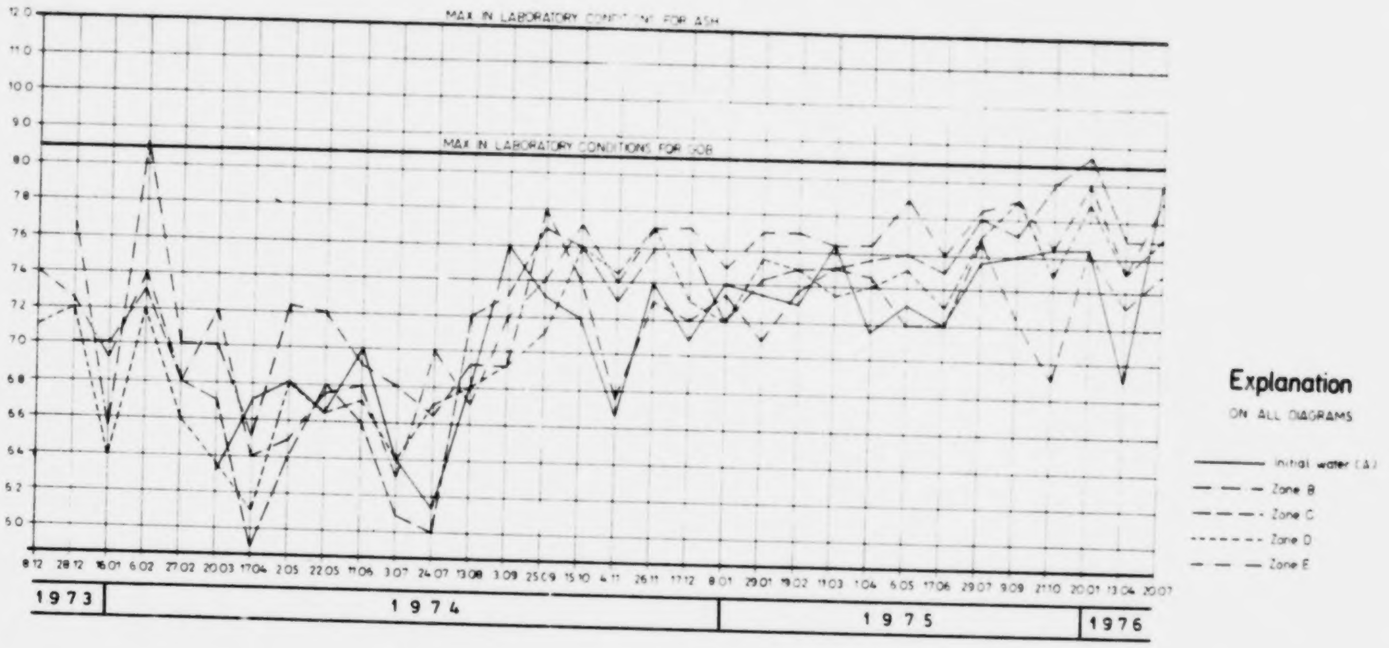


Fig. 8 DISPOSAL № 1. DIAGRAM OF pH REACTION

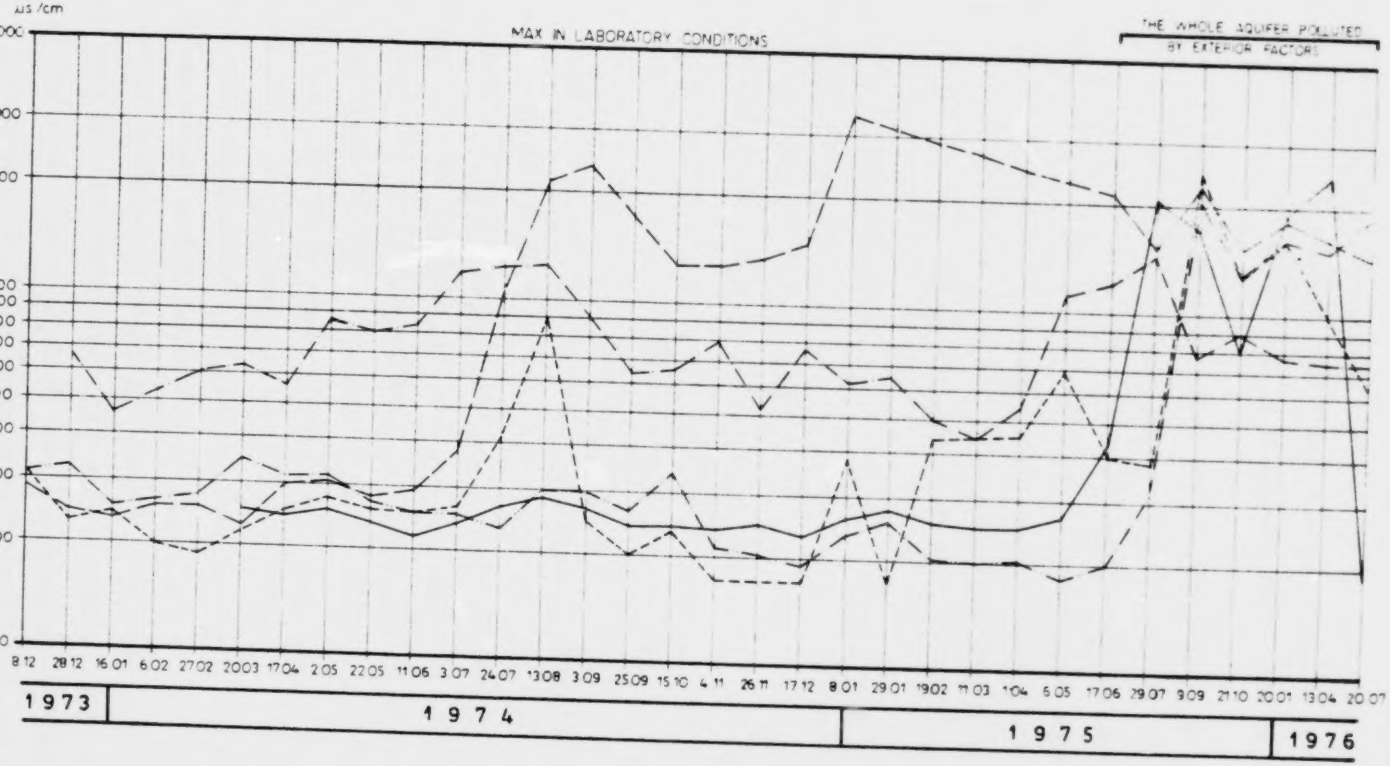


Fig. 9 DISPOSAL Nº 1. DIAGRAM OF CONDUCTIVITY

smaller, but marked itself distinctly in a form of appearing at about one month intervals waves of increased conductivity to the value of 400 - 900 μS/cm. On the other hand the increase in conductivity did not appear at all in wells situated in the zone E.

The conductivity of analysed waters displays dimensional and in time distribution wholly in agreement with the distribution of total dissolved solids. Derived from these tests a methodical conclusion is that for a quick, approximated evaluation of the water pollution, one can measure the value of conductivity and the achieved result (in μS/cm units) multiply by the coefficient 0,6 - 0,7 in order to obtain the sum of the dissolved substances in mg/l.

Total dissolved substances (Fig. no. 10) The content of dissolved substances in initial water during the main period of observations (18 months), to the June 17, 1975 fluctuated around the 200 mg/l limits. Respectively the maximum value acquired by laboratory leachates´ tests was 3000 mg/l. After the storage of waste material during the first month the sum of dissolved substances in the direct subsoil of the disposal (zone B) rose to about 300 mg/l, in order that during the next five months to achieve its maximum of about 850 mg/l. In the nineth month counting from the time of storing this value began gradually to decrease, and then oscillated within 300 - 600 mg/l limits. With about a 6-monthy delay a wave of polluted waters appeared in wells situated down the main stream (zone C) of the ground waters´ run-off. In this zone the maximum content of TDS appeared in the 8-th month beginning from the storing time (2000 mg/l) and this zone was characterized with highest TDS content up to the 18-th month of observations - these values during this time fluctuated within the 1000 - 2000 mg/l. In the zone D increase in the pollution of waters was much smaller and was indicating itself in a form of waves with the TDS contents of 250 - 500 mg/l. The influence of the disposal did not mark itself at all in the zone E. Comparison of the diagram of precipitation intensity with the diagram of total pollution (T.D.S.) indicates (particularly during the first period) a clear relationship of the

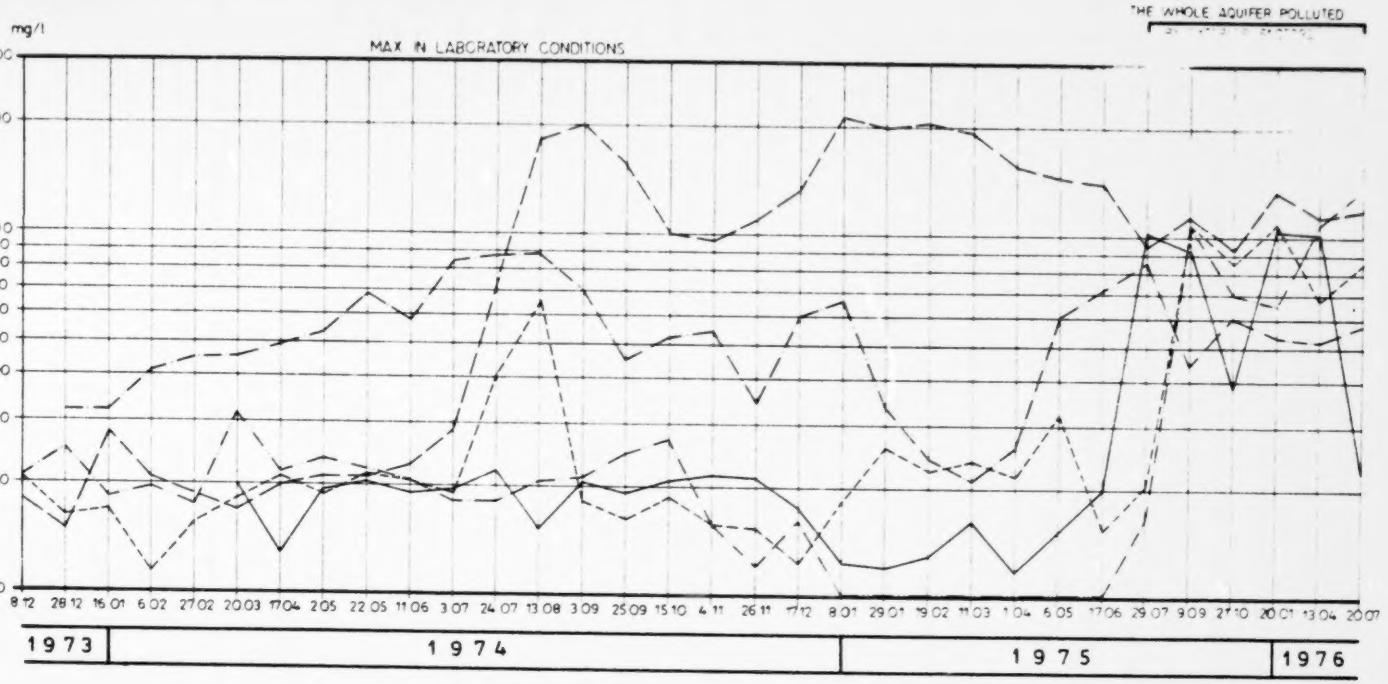


Fig.10 DISPOSAL Nº 1. DIAGRAM OF TDS CONTENT

amount of pollutions to the amount of precipitation. In a direct subsoil of the disposal the pollution appears after a delay of about 1 month (in relation to precipitation) and at further placed distances with a delay conforming to the velocity of underground waters´flow. In the subsoil of the disposal the pollutants appear already by relatively small precipitations, while outside the disposal only after a greater intensity of precipitations. After a longer period of the disposal existence a wave-wise relation smoothes itself out a little (waves interference) and the pollution occurs in a continuous form.

Content of the Cl ion (Fig. no. 11) - in initial water during the main period of observations the Cl content fluctuated within limits of 5 - - 15 mg/l, and the maximum value obtained in laboratory leachates´ tests amounted to 700 mg/l. In the direct subsoil of the disposal the Cl content in the whole period of observations was between values of 30 - 80 mg/l. With a delay of about 6 months the wave of increased Cl content appeared in the zone C. After a wave of intense precipitation in May, June and July an increase in this zone in content of Cl ion, from 12 mg/l value to about 160 mg/l, and later to 400 mg/l was found. Values of the 150-600 mg/l rank were maintained to the end of the main observation period, i.e. for 18 months. The disposal exerted also small, only a wave - form influence on the increase in chlorides in the zone D (content of the rank 20 - 100 mg/l) and no influence at all was found in further wells in the zone E. In June of 1975 the aquifer was subjected to a pollution with just the chlorides (NaCl) which caused their increase to over 1000 mg/l, and this period ceased to be representative for the investigations.

Nonetheless the investigations were continued to determine in the future the time relation of the durability of pollutions.

Content of SO_4 ion (Fig. no. 12) - this content in initial water fluctuated during the whole time period i.e. from the Dec. 1, 1973 to the July 21, 1976 within limits of 60 - 120 mg/l. Only two short periods occurred, where these values were of an order 160 - 200 mg/l. Maximum values obtained in laboratory conditions amounted to 2000 mg/l.

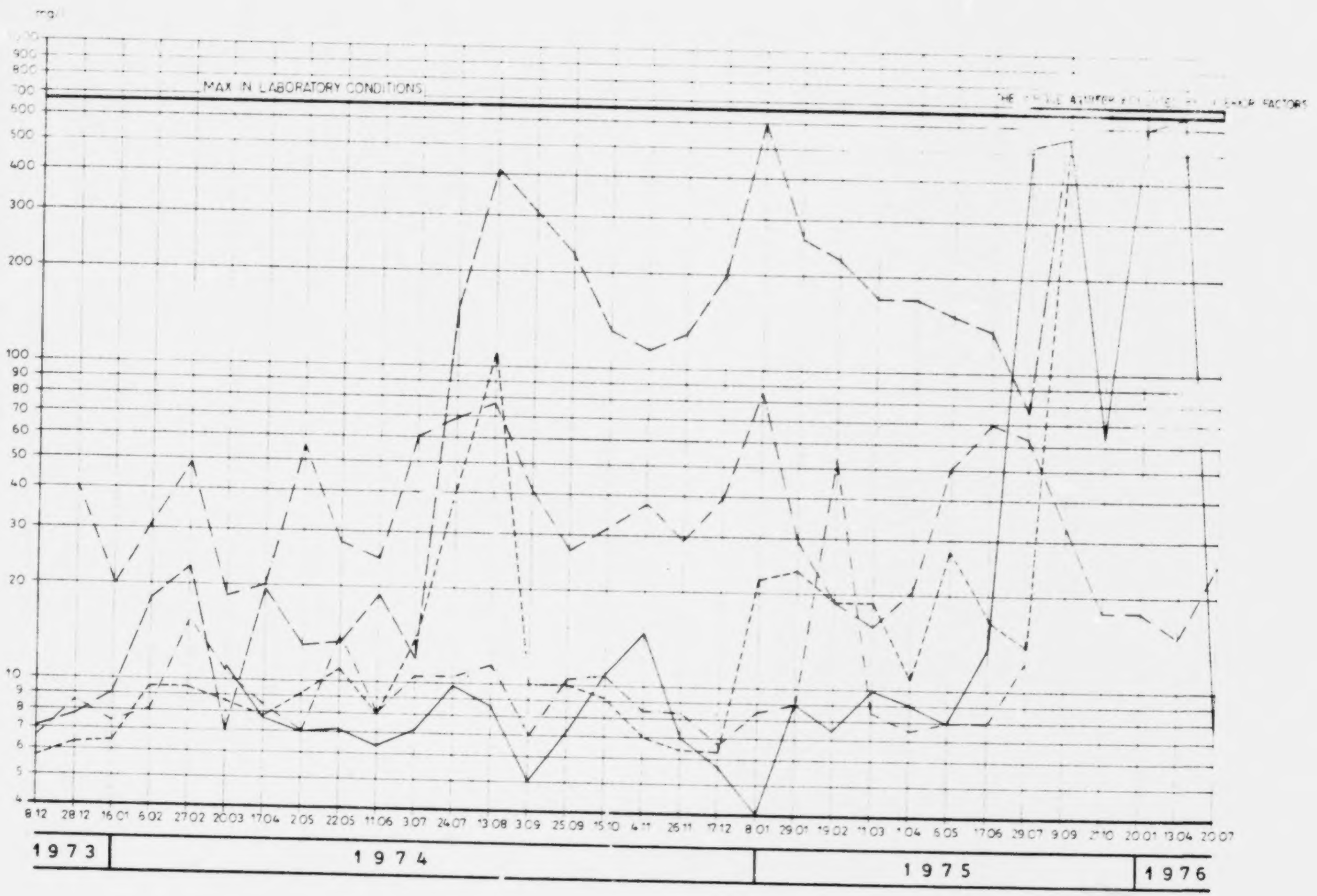


Fig.11 DISPOSAL. № 1. DIAGRAM OF Cl^- CONTENT

In the direct disposal's subsoil (zone B) an increased content of the SO_4 ion appeared during the first month after the storage (about 150 mg/l) and grew systematically to the end of July 1974 (i.e. for 7 months) achieving value of 400 mg/l. Following this wave - wise falls (to about 150 mg/l) and increases (to about 900 mg/l) were observed. In the zonc, an increased content of SO_4 ion appeared by the end of June, (therefore with about a 6 monthly delay), and obtained its maximum 900 mg/l in August 1974. Then after periodical fluctuations within limits of 200 - 600 mg/l again reached its maximum, 900 mg/l, in April 1975. In the remaining zones, i.e. zone D, and in the zone F, no clear rise in the SO_4, ion presence was noted. Very significant is the fact, that the extremely strong pollution aquifer under study by outside factors found its clear reflexion in analyses of the whole of dissolved solids and of chlorides, but in the case of SO_4 ion only a small increase in the SO_4 ion was recorded (mostly NaCl pollution).

Content of Na ion (Fig. no. 13) - this content in initial water during the principal period of observations from the Jan. 1, 1974 to the June 17, 1975 fluctuated within limits of 4-6 mg/l. (During the period of general pollution of the entire aquifer this content increased to about 350 mg/l, and this period could not be taken into consideration in our investigations). In laboratory conditions a maximum Na ion content of 600 mg/l was obtained. In the direct disposal's subsoil (zone B) almost immediately after the storage of waste material the content of Na ion increased to about 35 - 80 mg/l, and then kept on growing in order to arrive at its maximum after 6 months time (240 mg/l on the July 3, 1974). Following this, to the end of the main observation period it fluctuated within the limits of 50 - 150 mg/l. In the zone C certain minor symptoms of pollution appeared in the third month from the moment of the waste storage, and a systematic rise of the Na ion content in the fifth month occurred. A maximum Na ion content appeared after 9 months (450 mg/l) and after a periodical fall to the rank of 60 - 100 mg/l, again increased, and between eleventh and eighteenth month stayed on the 350 - 500 mg/l level. Very interesting also is the

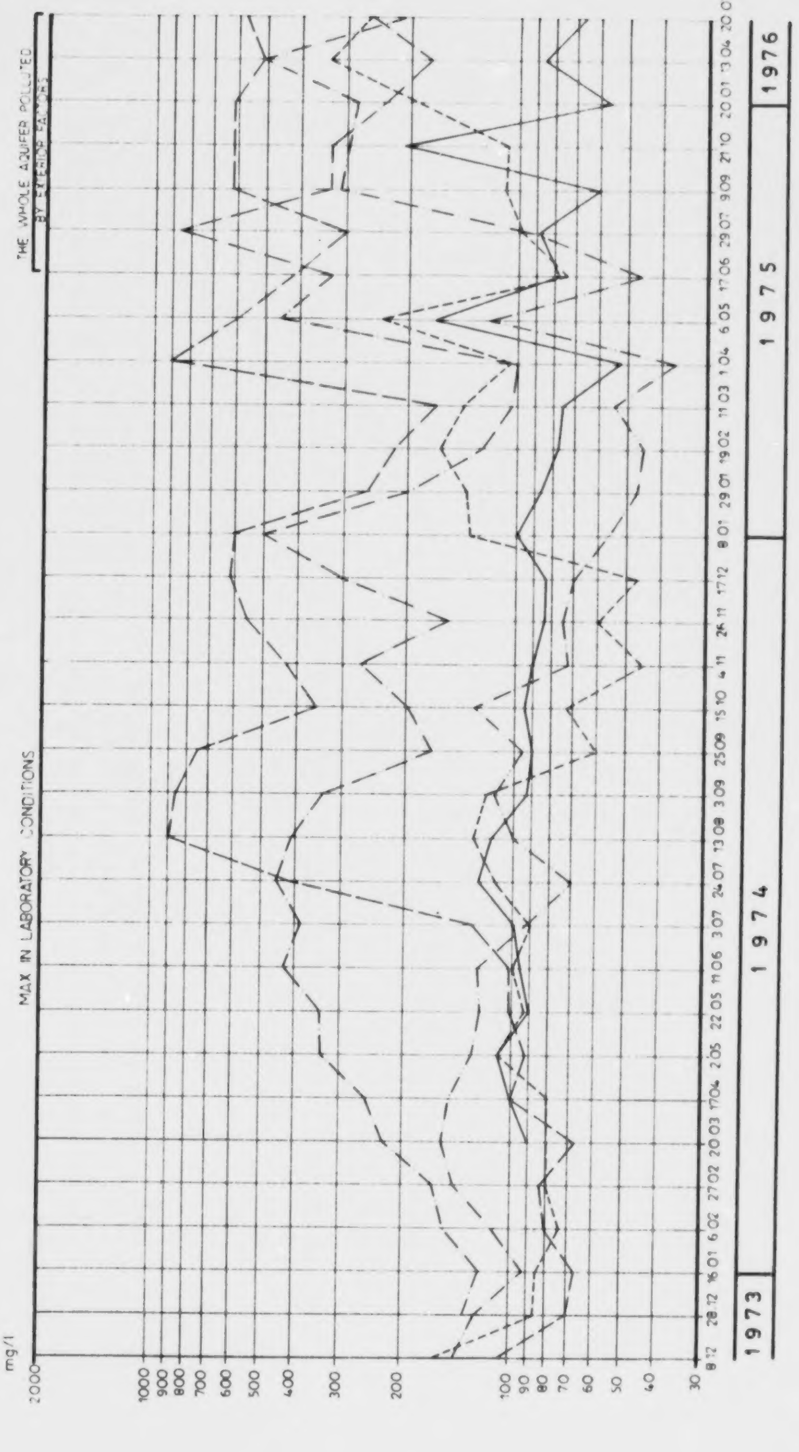


Fig.12 DISPOSAL Nº 1. DIAGRAM OF SO_4^{-2} CONTENT

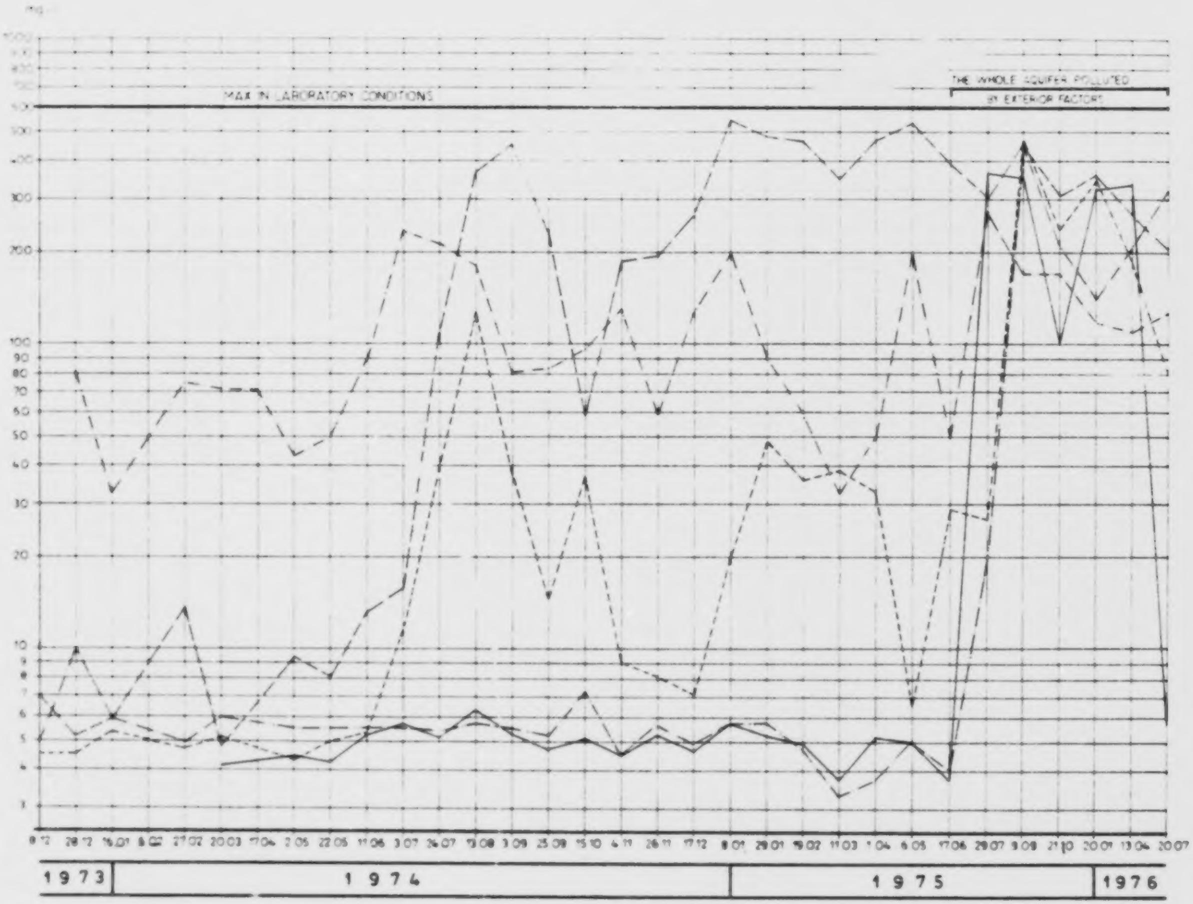


Fig.13 DISPOSAL № 1. DIAGRAM OF Na CONTENT

course of the phenomenon in the intermediate zone D. After an initial lack of influence of the disposal on waters of this zone this appeared very clearly in the sixth month from the storage of waste material. The content of Na ion increased then from 5 to 120 mg/l and for the whole time of observations stayed within 7 - 50 mg/l limits therefore considerably higher than in initial waters. These observations confirmed fully the significance of greater mobility of Na ion in relation to other ions and brought to the conclusion, that every forecast of the migration phenomena cannot have a universal character and must take into account entirely different behaviour of various ions. All employed general methods may only give a close approximation of the phenomenon.

No increased content of the Na ion at all was observed in the zone E.

Content of K ion (Fig. no. 14) - in initial water during the principal period of observations fluctuated within limits of 1,5 - 3 mg/l, and in laboratory conditions within the 37 mg/l limit for gob and 400 mg/l for ashes. The increase in K ion in the direct subsoil of disposal was slower than in case of Na ion, and its maximum (18 mg/l) appeared with a one month delay. Later on this value decreased to the order of 6 mg/l and again rose to about 18 mg/l. In the zone C a more distinct presence of the K ion (10 mg/l) was ascertained also with an one month delay (Aug. 13, 1974) in relation to Na ion, and maximum in amount 60 mg/l was observed with a three monthly delay. In the zone D and in the zone E practically no increased content of K ion was observed. Observations of the K ion lead to the conclusions that:

- a much smaller quantity of K ion in relation to its potential content in the waste material passes in given time to ground waters than of Na ion

- mobility of the K ion within the aquifer is much smaller

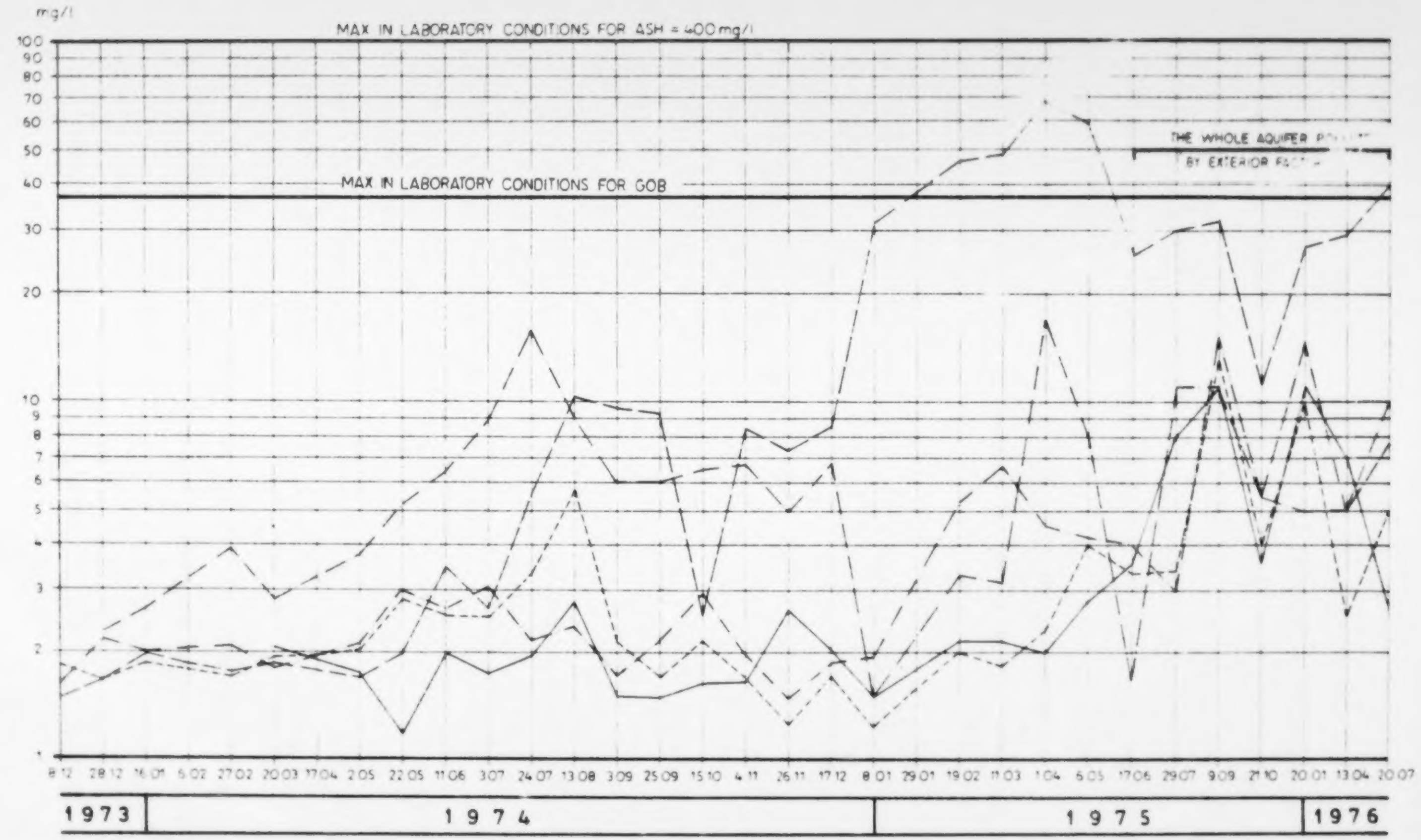


Fig.14 DISPOSAL Nº 1. DIAGRAM OF K CONTENT

- the forecasting of migration of both ions, Na and K, with the same modelling or numerical methods as in the world practice is used is not well founded, and may lead to errors.

Content of Ca ion (Fig. no. 15) - in initial water during the main period of observations (18 months) fluctuated within limits of 20 - 45 mg/l and maximum obtained in laboratory conditions was 900 mg/l (for ashes). In the direct subsoil of disposal an increased Ca content (65 mg/l) appeared already in the first month after the storage; the first maximum was achieved after 4 months (120 mg/l), in order, after a periodical decrease (to 30 mg/l), to achieve a subsequent maximum in the ninth month (110 mg/l). Following this the Ca content fluctuated within limits of 40 - 70 mg/l with a slow tendency to decrease. In the zone C the increase in the Ca content was noted from the 3-rd of July, in order to achieve the maximum, 250 mg/l, in the ninth month. Subsequently, the Ca ion content in waters of this zone stayed on the level of 80 - 200 mg/l with a clear tendency to fall. In the zone D and zonE no distinct increase in the Ca ion content was noted in reference, to the disposal influence, a fact that speaks for a small mobility of the Ca ion. Attention also draws the fact, that in relation to the potential possibilities (900 mg/l) a proportionally small quantity of Ca ion in field conditions passed to ground waters (max. 250 mg/l),

Content of Mg ion (Fig. no. 16) - in initial water shows a much greater rate of fluctuation and irregularity than is the case with other ions. These values fluctuate within limits of 1, 2 mg/l to 21 mg/l and this span is similar as is case of waters in the direct subsoil of the disposal (2,5 to 21 mg/l), or in waters in the zone C (1 to 41 mg/l). Although difficult is the specify quantitatively the influence of the disposal, unquestionable is that this influence indicates itself through the fact, that waters of zone with the greatest predisposition to pollution, are actually characterized with highest, about 2 -times, greater content of Mg ion in relation to initial water, but show a tendency to decrease with time.

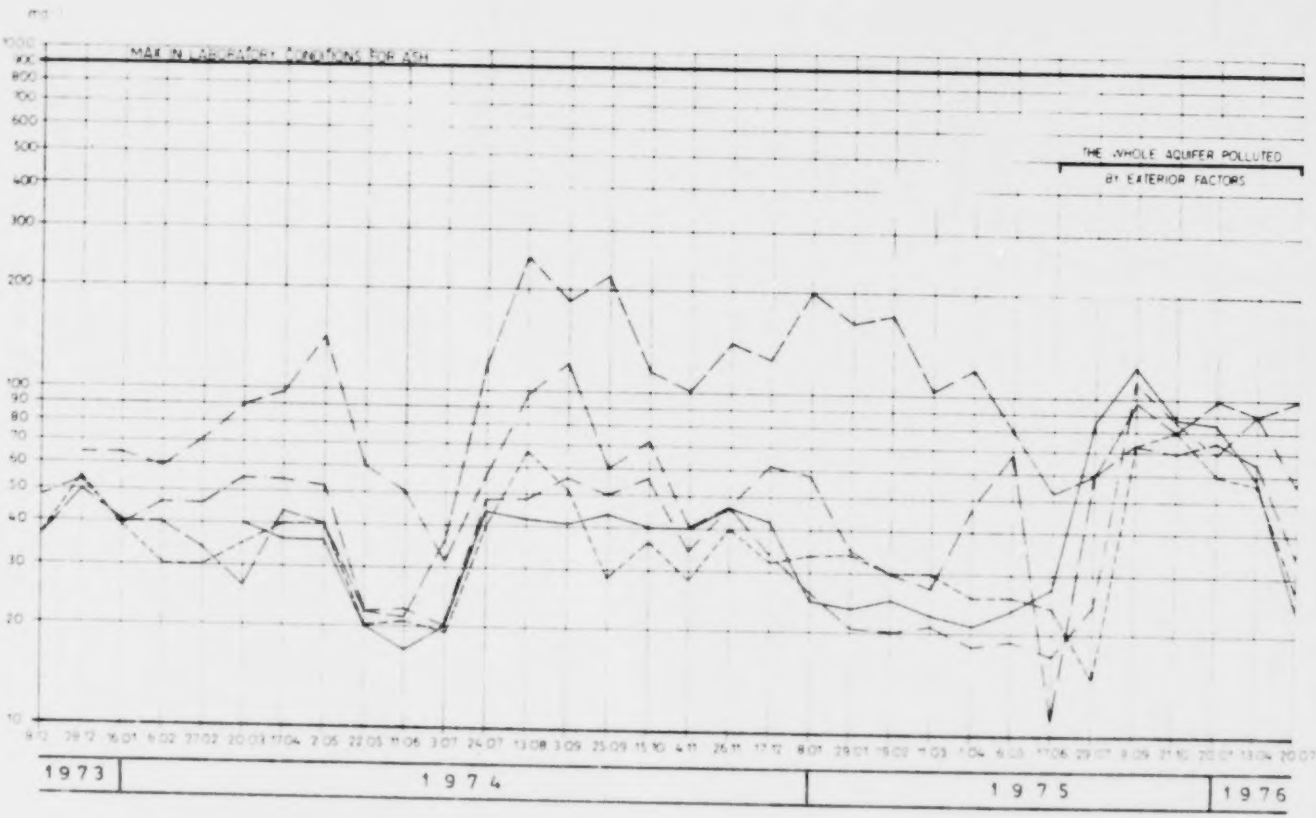


Fig.15 DISPOSAL №1 DIAGRAM OF Ca CONTENT

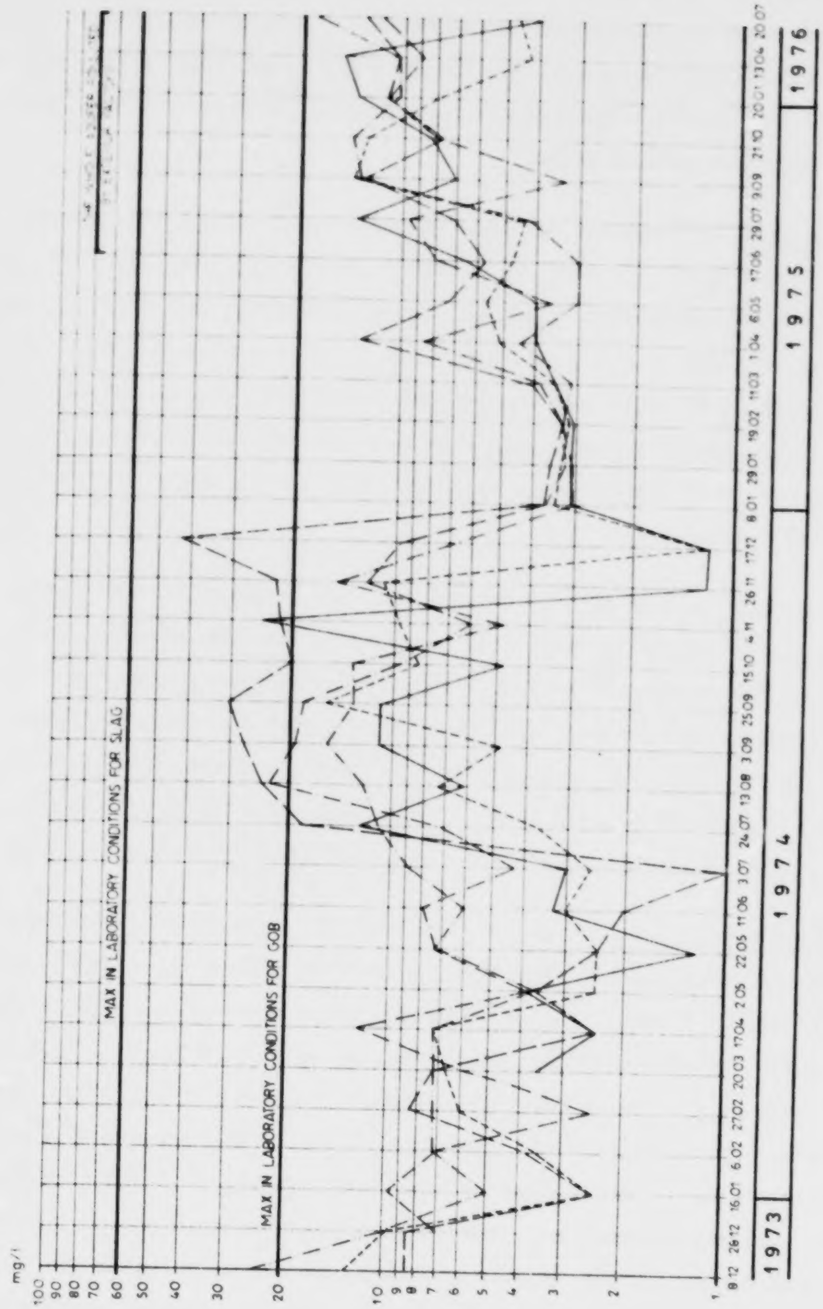


Fig.16 DISPOSAL Nº1. DIAGRAM OF Mg CONTENT

Content of Fe ion (total iron) - fluctuates in all waters within limits of 0,01 to 1,3 mg/l; no connection between the disposal existence and the content of iron is observed however; the higher encounted values than average ones and those characterizing initial water happen in disorderly fashion both in time and in locations and should be considered as an incidental occurrence.

Content of Mn ion - content of manganese fluctuates extremely in initial waters, from 0,05 to 0,9 mg/l and it seems, although not with full clarity, that the disposal had, especially during the first period of observation, a certain small influence on the increase of this ion in its direct subsoil. It is difficult to specify univocally this phenomenon in quantitative categories, although on the whole all waters collected from the wells were indicating a couple of times greater Mn contents than the initial water.

Ammonium ion (NH_4) content - fluctuates extremely within limits of 0,03 - 1,8 mg/l. It appears that the presence of the disposal effects an increase in the content of this ion, the expression of this is the fact that in zones, which are affected strongest by the disposal, therefore in its direct subsoil and zone C there is number of times greater content of ammonium ion than in initial waters, and also is 2-3 times greater than in waters of the zone D and in the zone E.

Content of phosphate ion (PO_4) reached in laboratory leachates 5 mg/l but in ground waters fluctuates within limits of 0,002 to 0,072 mg/l. A clear 2 to 8 times greater increase in the PO_4 content to compare with other wells is observed in the well P-11, this in both versions of sampling - in relation to initial water and to other wells. This can prove that the source of phosphate pollution of waters are the ashes prevailing in the area of the well P-11, but this pollution, taking things quantitatively is minimal beacuse is reflected much weaker in zone C, and none at all is observed in other zones. It is very difficult to say why so small amount of PO_4 ion has been leached to ground water to compare with laboratory tests. It could be that PO_4

ion requires much more water to be leached and it is an ion very difficult to mobilize.

Content of Al ion (Fig. no. 17) - both in initial waters and in waters influenced by the disposal fluctuated within limits of 0,01 to 0,6 mg/l, whereby this variability had a time character and not dimensional. Therefore this can be stated that disposal had no influence on the Al ion content in ground waters affected by it, the more so as the respective maximum value obtained in laboratory leachates was 0,4 mg/l value (except one test where it was 2 mg/l).

Content of cyanides (CN) (Fig. no. 18) - in initial waters fluctuated within 0,0002 to 0,004 mg/l limits. (One sample was 0,011 mg/l). In waters of the disposal's direct subsoil, zone B, in the first year of observations the corresponding values fluctuated within 0,003 to 0,02 mg/l limits, therefore were about 10 times higher. In a somewhat lesser degree an increased (0,0008 to 0,008 mg/l, i.e. about 3-fold) content of cyanides was found in the zone C. Also a little higher value, although in still small quantity this was encountered in the zone D. Therefore in all, seems that the disposal had influence on the increase in the cyanide content in the zone of its influence, to about 10 times, for which is speaking also the parallelism of curves on the enclosed diagram (totting up the cyanide contents). During the second year of observations, as already known, a general pollution of the entire aquifer took place, and this period cannot be taken into account in arriving at conclusions.

Content of phenols in initial water fluctuated within 0,01 to 0,2 mg/l limits. In waters of the direct subsoil of the disposal zone B and zone C as well, also in the zone D these values as a rule were little higher. Omitting single cases observed about 2-fold increase was in the contents of phenols. Typical was, that during the period of pollution of entire aquifer horizon the content of phenols rose only minimally, and during that time their content in initial waters was higher than in waters remaining under the influence of the disposal. This very small influence if any of the disposal on phenols content confirm

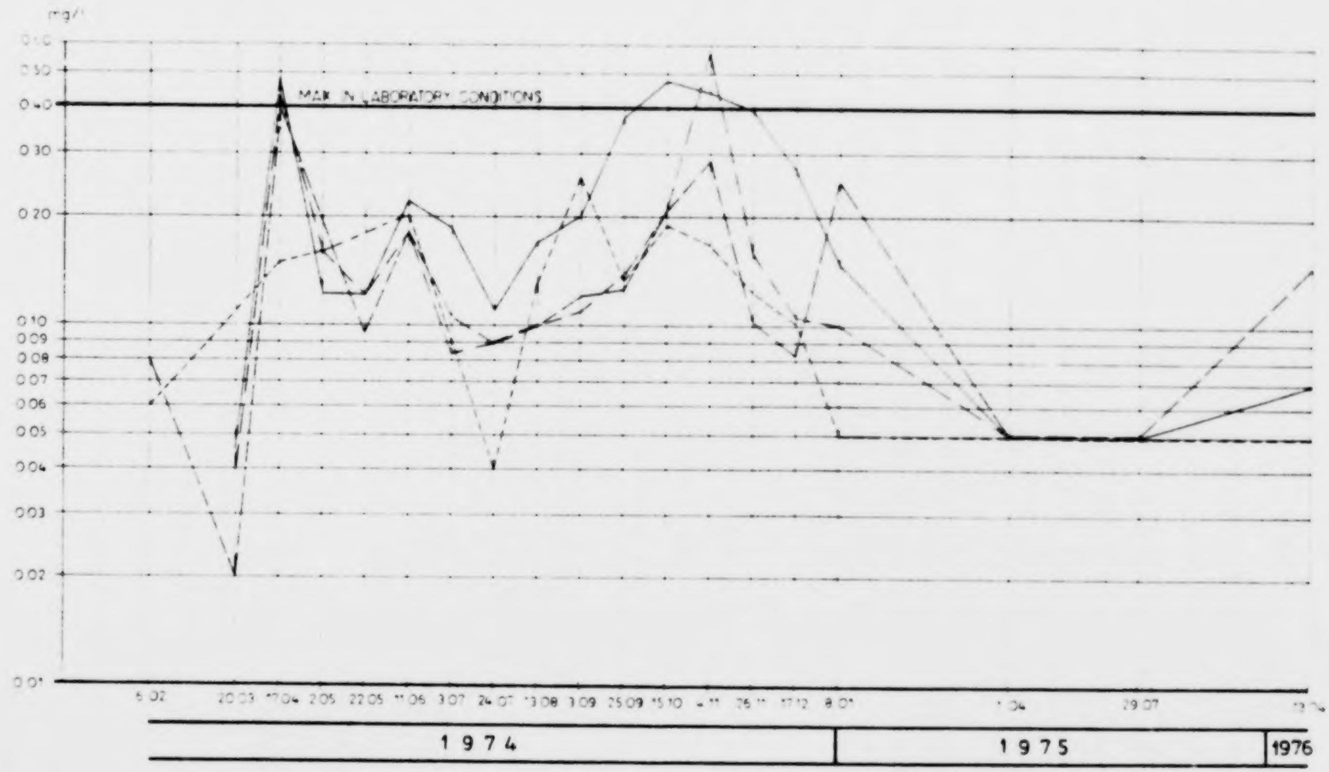


Fig.17 DISPOSAL №1. DIAGRAM OF Al CONTENT

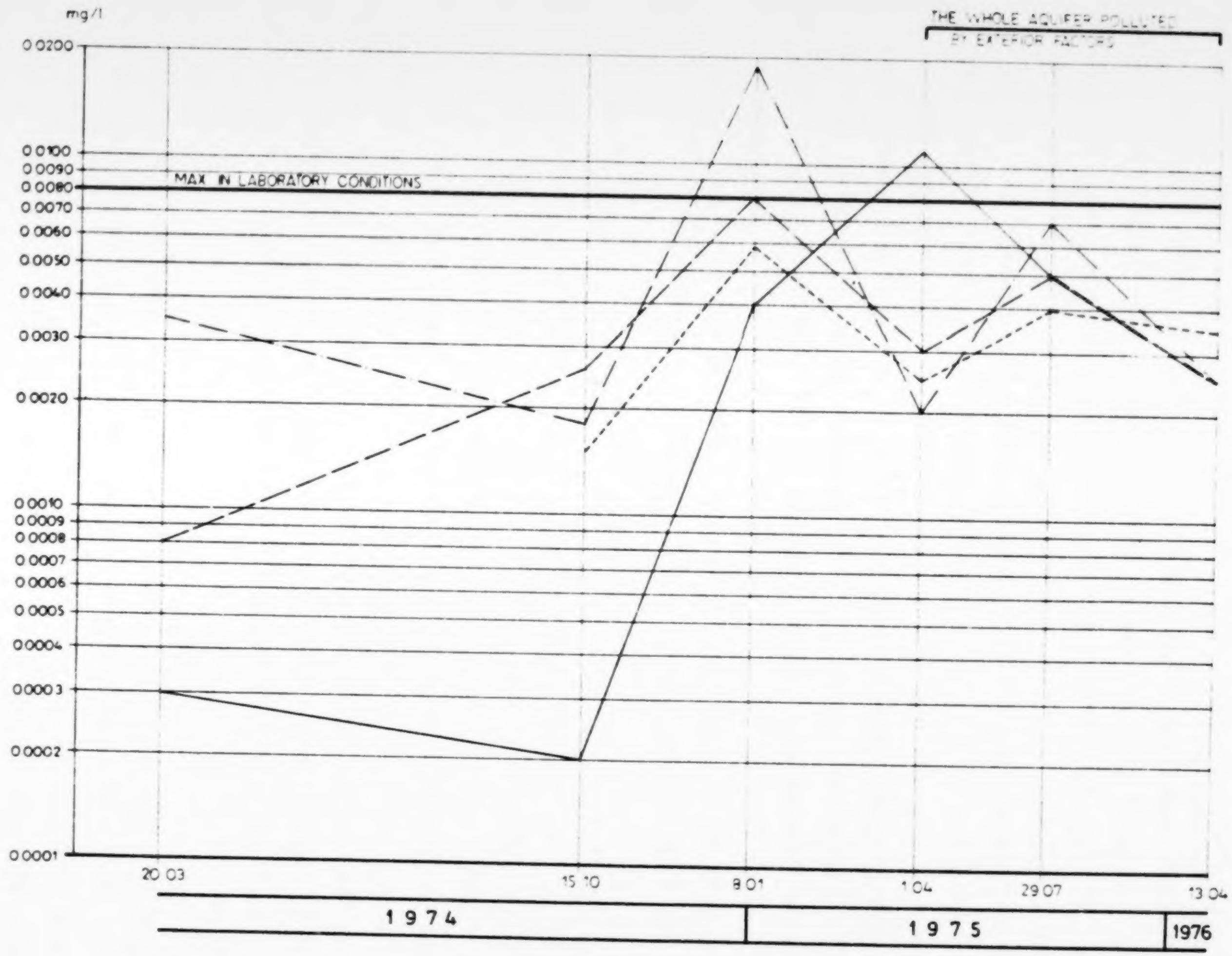


Fig. 18 DISPOSAL Nº 1. DIAGRAM OF CN CONTENT

also their small content in laboratory leachates which was considered below 0,022 mg/l.

Content of the Cu ion (Fig. no. 19) - in initial water fluctuated within 0,001 to 0,006 mg/l limits (during the period of general pollution of the aquifer it rose to 0,03 mg/l), in laboratory leachates the presence of Cu ion was found in quantity 0,034 mg/l. In the zone of direct disposal subsoil the Cu ion content fluctuated within the same limits as in initial water and in a similar time period. Clearly increased however contents of the Cu ion were found in the zone C directly downstream of ground waters, where respective values were from 0,002 to 0,44 mg/l and in the time aspect were 2 to 5 times greater from respective values for initial waters. Parallelism of curves on the enclosed diagram indicates a clear addition of the Cu ion content along the width of water flowing under the disposal. This proves furthermore that presence of the disposal most probably causes the increase in the Cu ion content in ground waters from 2 to 6 times.

Content of the Zn ion (Fig. no. 19) - in the initial water fluctuates within the 0,004 to 0,05 mg/l,in laboratory leachates 0,06 to 0,13 mg/l limits, and in ground waters from 0.007 to 0.14 mg/l. Analysing however the spatial and time aspects of these values one can say, that only 2 from 4 series of analyses did indicate increased content of the Zn ion in the subsoil of the disposal and in the zone C, also in zone D, while 2 remaining series did not indicate this phenomenon. The fifth series was disregarded, where clearly was indicated pollution of the entire aquifer. In the light of the above the influence of the disposal is almost sure.

Content of the Hg ion (Fig. no. 20) - in initial waters fluctuated within 0,1 to 0,8 μg/l limits, in laboratory leachates within 3 μg/l (ash) to 5.4 μg/l (gob.). In the subsoil of the disposal this value was almost the same, and in the zone C little higher periodically. Higher values were observed also periodically in the remaining zones for this reason difficult is to give an unequivocal answer regarding to what extent the disposal effects the mercury increase in,but the fact of influence on

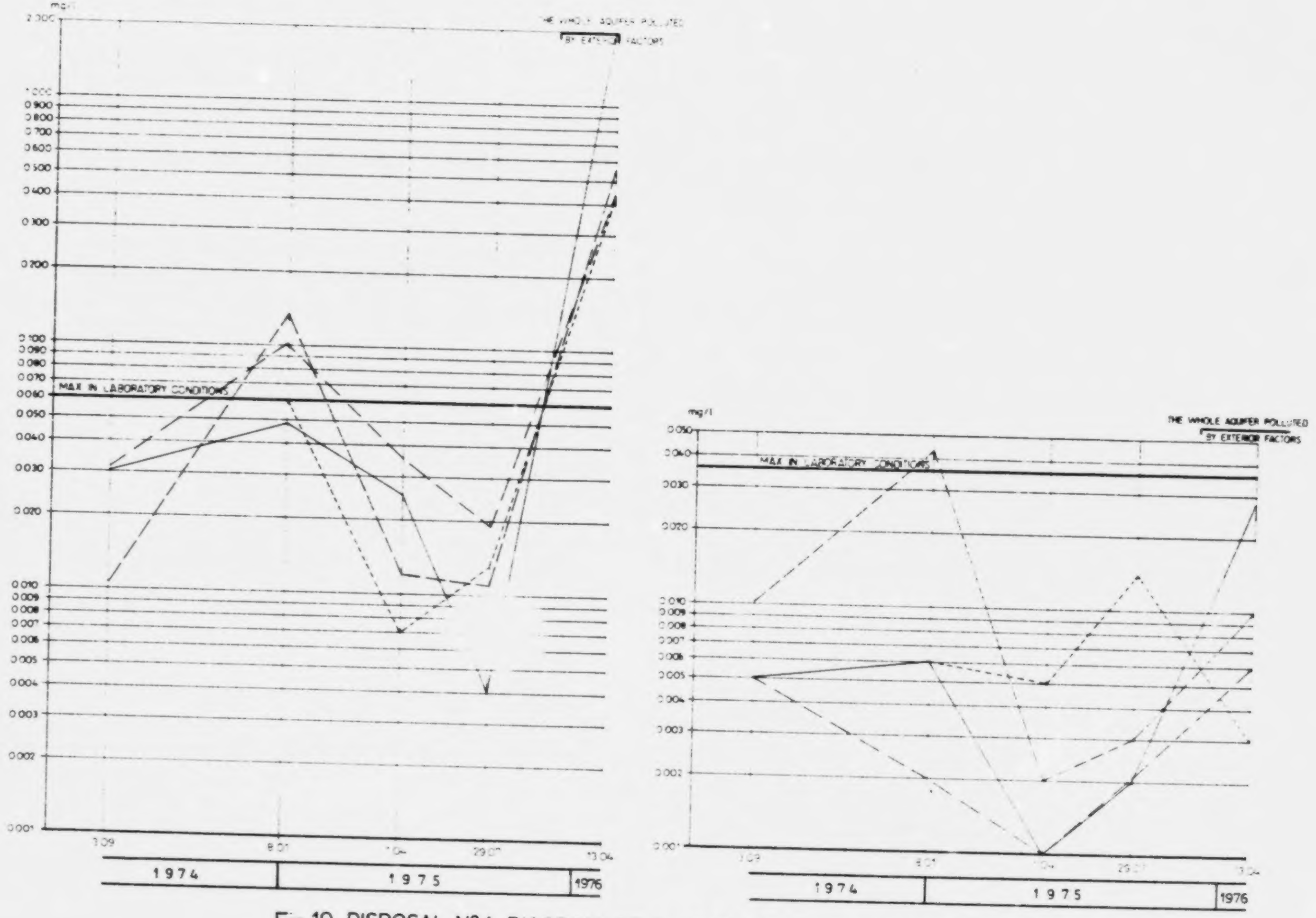


Fig.19 DISPOSAL Nº1. DIAGRAM OF Zn (left) AND Cu (right) CONTENTS

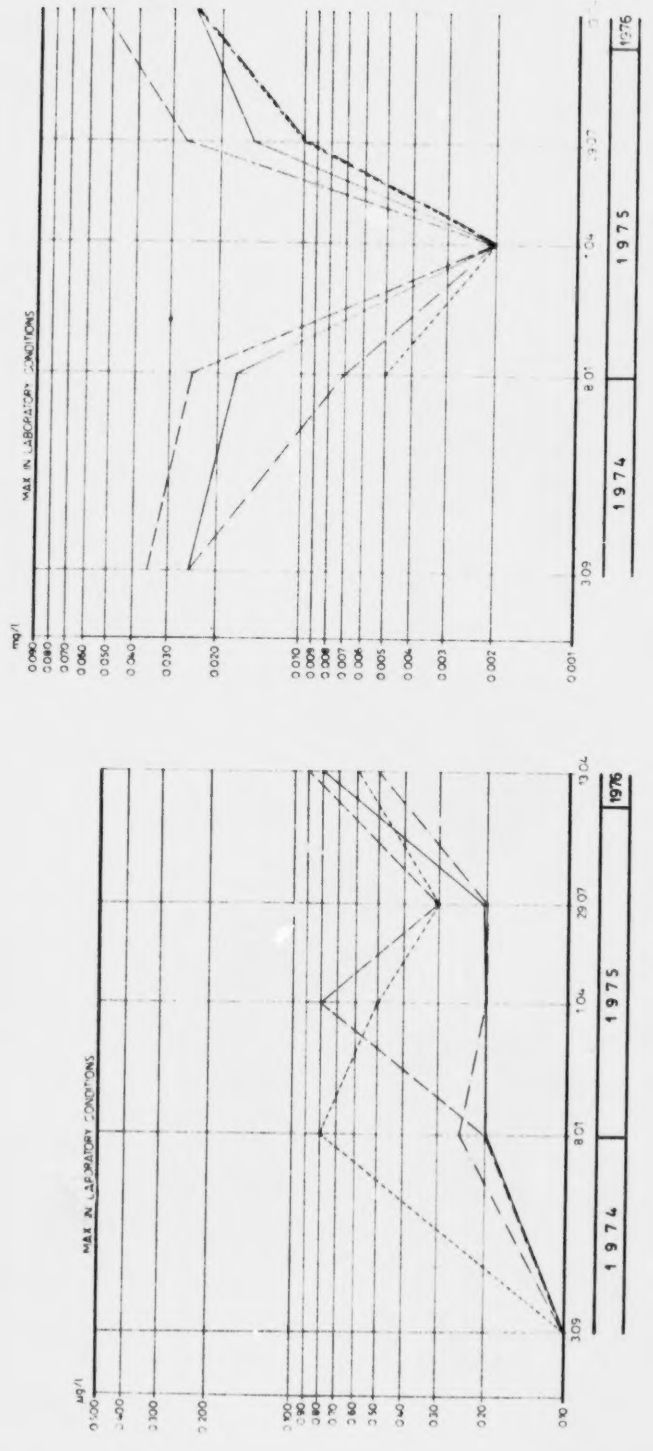


Fig.20 DISPOSAL №1. DIAGRAM OF Hg (left) AND Pb (right) CONTENTS

ground waters is almost sure. Quantitative assumption is difficult as the laboratory leachates indicated the high content of mercury.

Content of Pb ion (Fig. no. 20) - in initial waters fluctuated within 0,002 to 0,025 mg/l, in laboratory leachates to 0.081 mg/l limits. Small only increase was found in the ground waters (to 0.05 mg/l, only in the zonc). One has no clear indication as to the influence of the disposal on increase in the lead content in ground waters, although the existence of such influence with a small rate (2 times) is very possible.

Content of As ion (Fig. no. 21) - fluctuated in initial water within 0,001 to 0,01 mg/l limits, in laboratory tests it reached 0,1 mg/l. In ground waters remaining under the influence of the disposal periodically observed were increased amounts of As ion within limits reaching maximally 0,033 mg/l, which would indicate that the disposal influenced the increase of about 3 times.

Content of Sr ion (Fig. no. 21) - in initial waters fluctuated within the 0,056 to 0,090 mg/l limits (higher value could be resulted from the general pollution of the aquifer. Laboratory leachates showed the values up to 1.5 mg/l. Respective values for waters under the disposal fluctuated within 0,15 to 0,32 mg/l limits (therefore about 3 times greater), for the waters of the zone C within limits of 0,25 to 0,5 mg/l (therefore 5 times greater), and for waters of the zone D within 0,08 to 0,12 mg/l limits (about 40 % greater). The above data prove a clear influence of the waste disposal on increased content of strontium in ground waters and high mobility of Sr ion both in solubility as well as within aquifer.

Content of Cd ion (Fig. no. 22) - in initial waters fluctuated around the 0,002 mg/l values (higher 0,008 mg/l value was probably connected with a general pollution of the aquifer),whilst in laboratory tests maximum value 0,02 mg/l was obtained. In waters of zones remaining under the influence of the disposal noted were in many cases increased quantities of the Cd ion, which seems to indicate that this ion is passing from the disposal to ground waters.

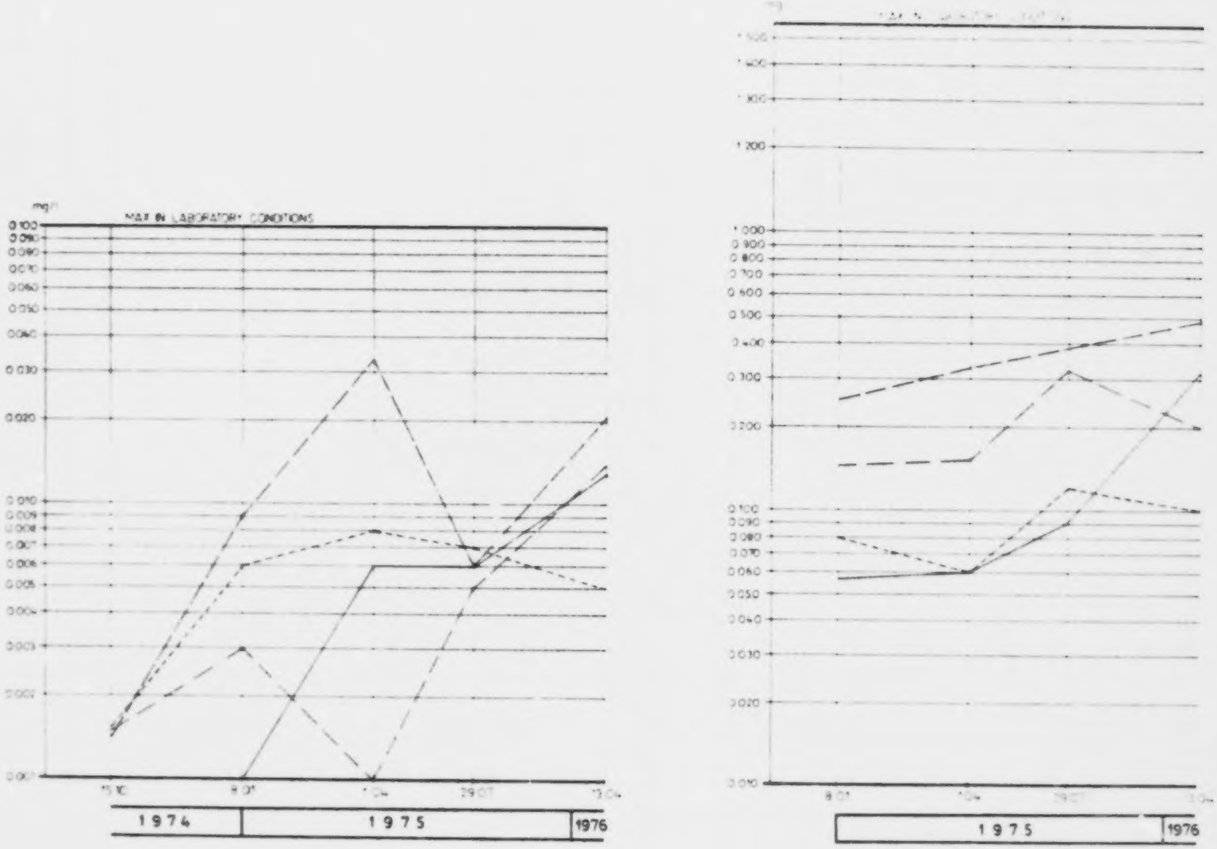


Fig 21 DISPOSAL Nº1. DIAGRAM OF As (left) AND Sr (right) CONTENTS

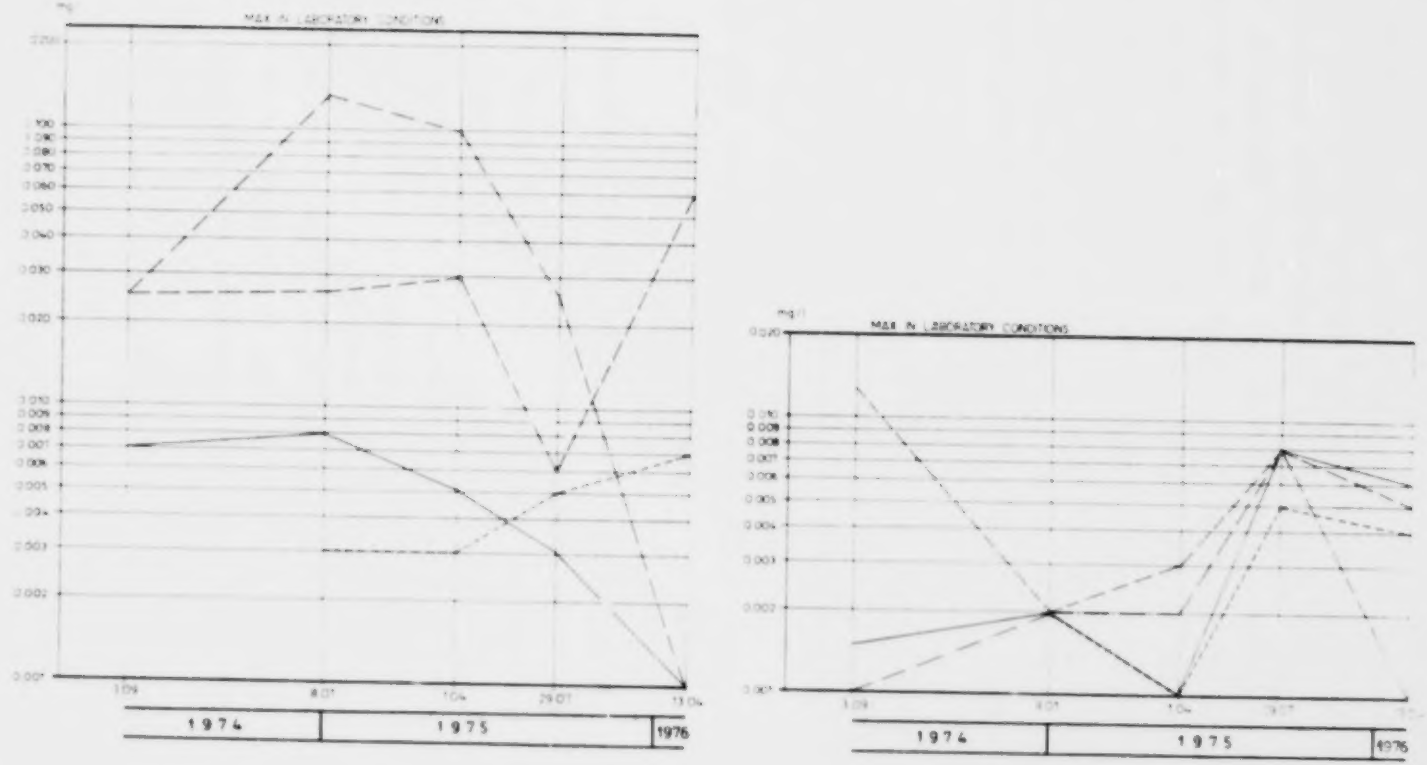


Fig. 22 DISPOSAL №1 DIAGRAM OF Mo (left) AND Cd (right) CONTENTS

Content of Mo ion (Fig. no. 22) - in initial water fluctuates within the 0,008 to 0,001 mg/l limits and indicates a clear downward tendency with time. In laboratory leachates it ammounted up to 0,23 mg/l in ash and only to 0,034 mg/l in gob. Observed was a very pronounced increase in the molydbenum content in the direct disposal´s subsoil (0,02 to 0,12 mg/l, therefore about 15-fold) and also in the downstream zone C of the ground waters (0,025 to 0,070 mg/l, i.e. almost 10-fold greater). This influence manifested itself also in the zone D although with a great delay of time. On the whole the disposal did exert a clear and serious influence on the increase in the content of molybdenum in ground waters. It shows also high mobility of this ion.

Content of Cr ion (Fig. no. 23) - in initial water fluctuated within 0,003 to 0,028 mg/l limits, in laboratory leachates this was 0,067 mg/l (in ash) and in ground waters influenced by the disposal was from 0,002 to 0,016 mg/l. These values show that there no connexion exists between the Cr ion content in ground waters and the disposal presence.

Content of B ion (Fig. no. 23) - in initial water fluctuated within the 0,02 to 0,09 mg/limits. In laboratory leachates it was found up to 7,2 mg/l in ash and up to 1 mg/l gob. Respectively in the direct subsoil of disposal B content within limits of 0,1 to 0,46 mg/l, and in the zone C of from 0,55 to 2 mg/l, and in the zone D within limits of 0,06 to 0,02 mg/l. The above values and also the parallelism of diagrams show a clear connection existing between the presence of the disposal and the increased about 25 times content of the boron ion in ground waters. The potential pollution by boron is extremely high especially in the case of ash as well as the mobility of B ion is wery high.

MASS ANALYSIS OF MAIN POLLUTANTS LEACHED FROM THE DISPOSAL

Main components (omitting the quantitatively insignificant, yet qualitatively harmful heavy metals) polluting the ground waters in the area

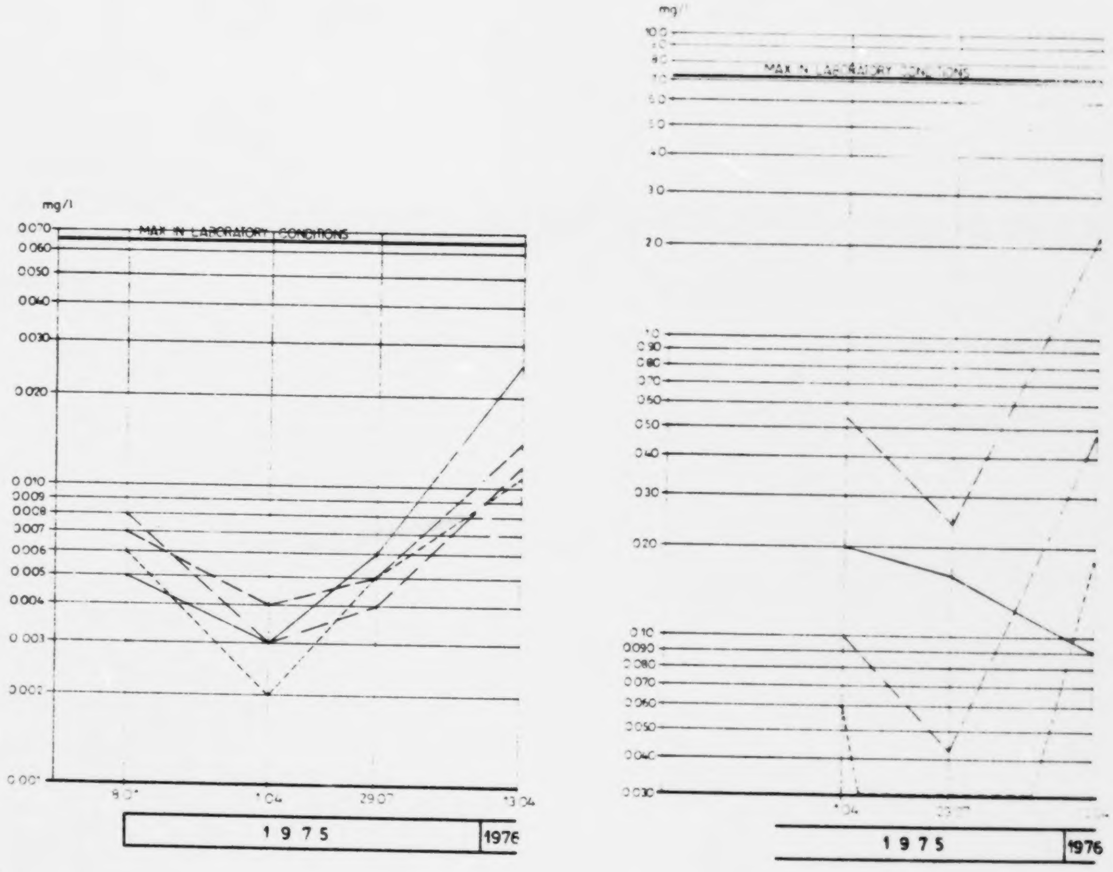


Fig. 23 DISPOSAL №1. DIAGRAM OF Cr (left) AND B (right) CONTENTS

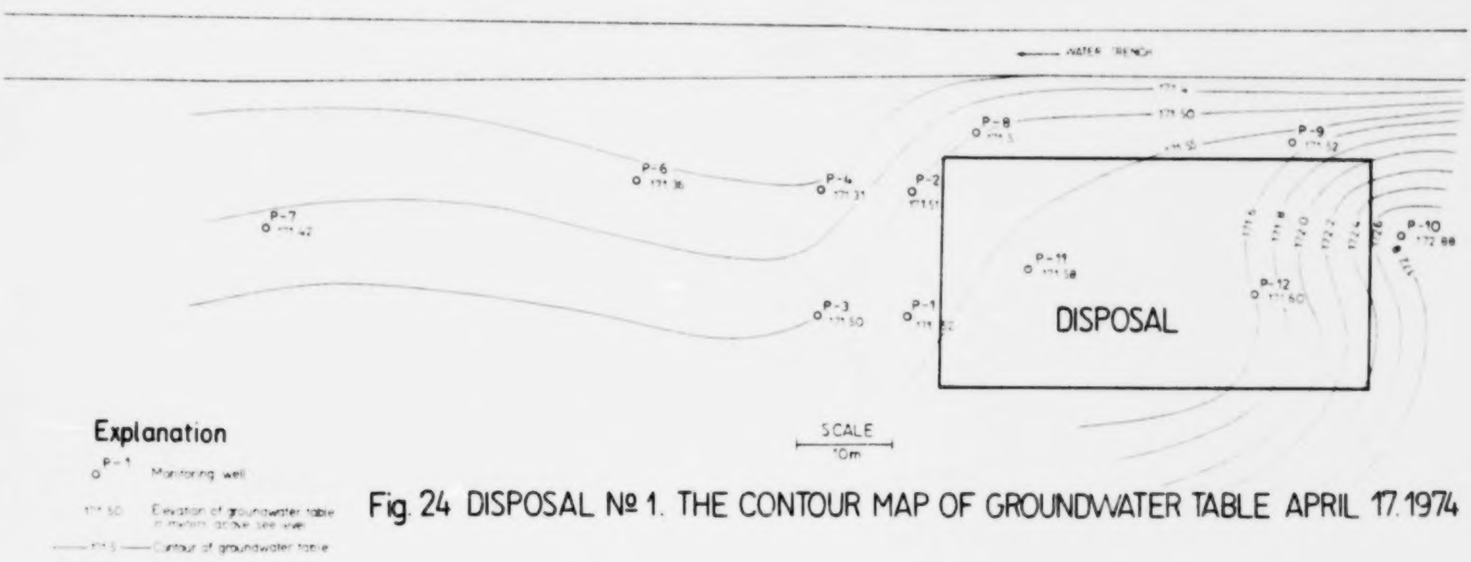


Fig. 24 DISPOSAL № 1. THE CONTOUR MAP OF GROUNDWATER TABLE APRIL 17.1974

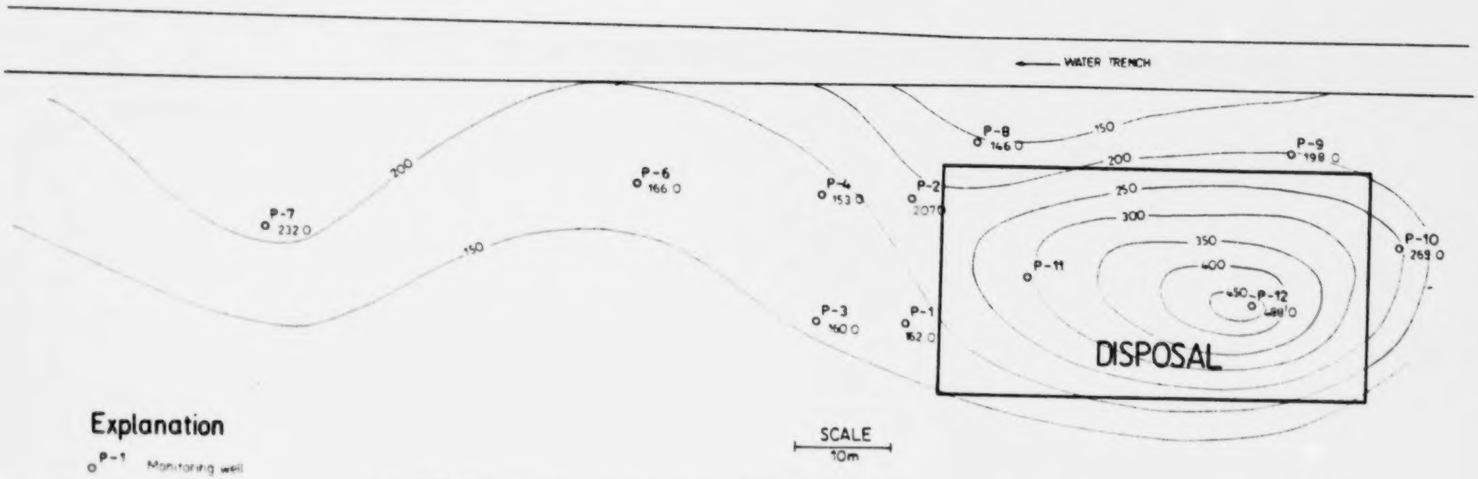
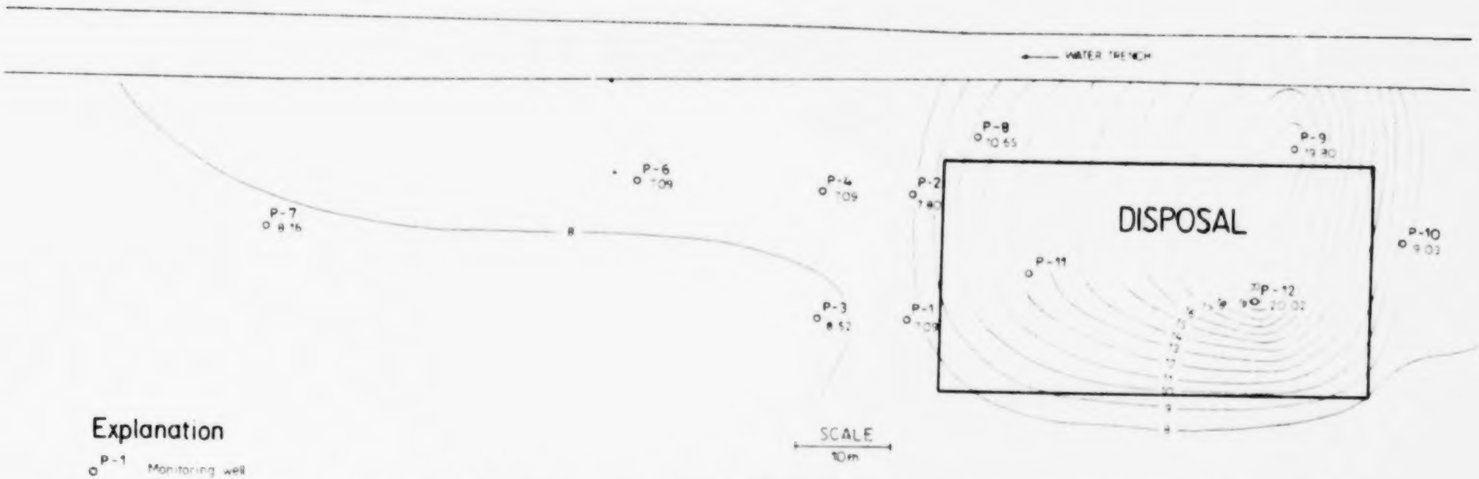


Fig. 25 DISPOSAL № 1. THE CONTOUR MAP OF TDS CONTENT APRIL 17.1974



Explanation

o^{P-1} Monitoring well

7.09 Cl⁻ content in mg/l

—— 8 —— Contour of Cl⁻ content

Fig. 26 DISPOSAL № 1. THE CONTOUR MAP OF Cl⁻ion CONTENT APRIL 17 1974

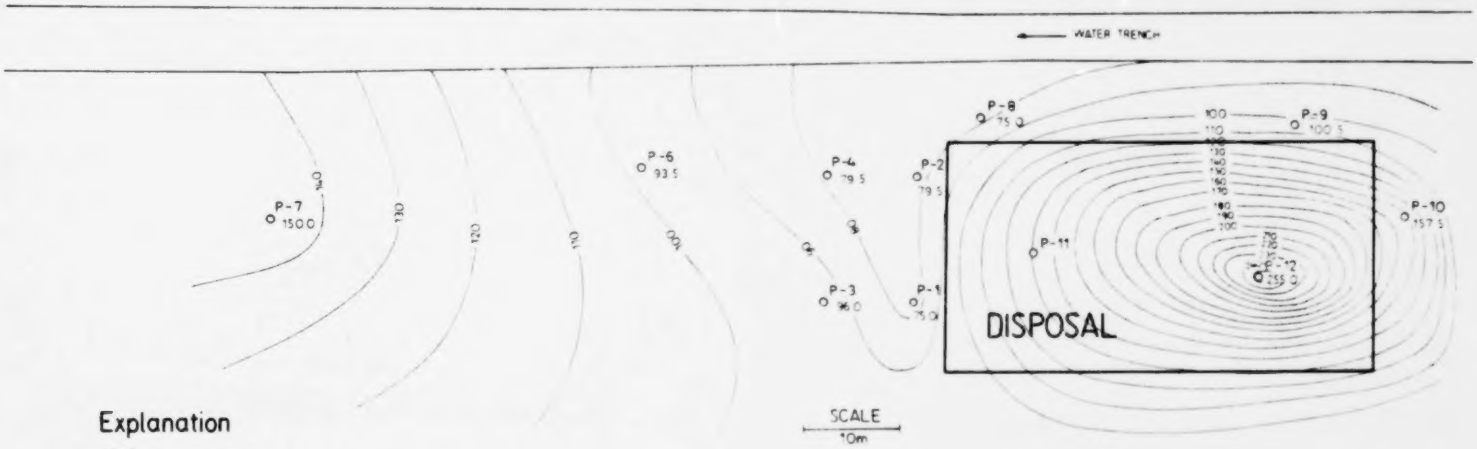
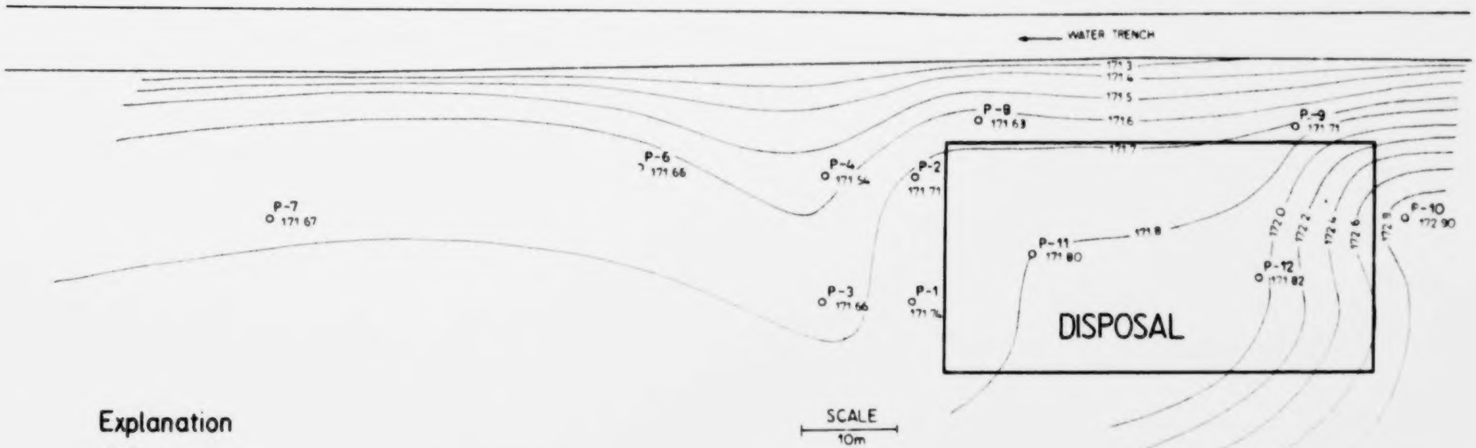


Fig. 27 DISPOSAL № 1 THE CONTOUR MAP OF SO_4^{-2} ion CONTENT APRIL 17. 1974



Explanation

P-1 Monitoring well

171 74 Elevation of groundwater table in meters above see level

—171 8— Contour of groundwater table

Fig. 28 DISPOSAL № 1. THE CONTOUR MAP OF GROUNDWATER TABLE AUG. 13.1974

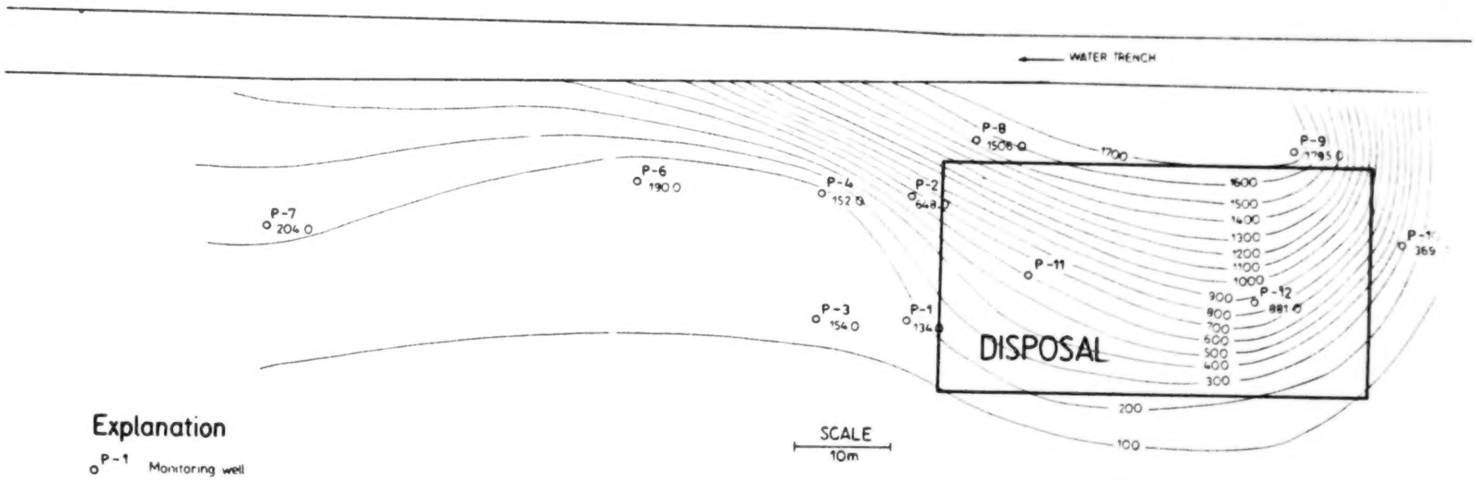


Fig. 29 DISPOSAL № 1. THE CONTOUR MAP OF TDS CONTENT AUG. 13. 1974

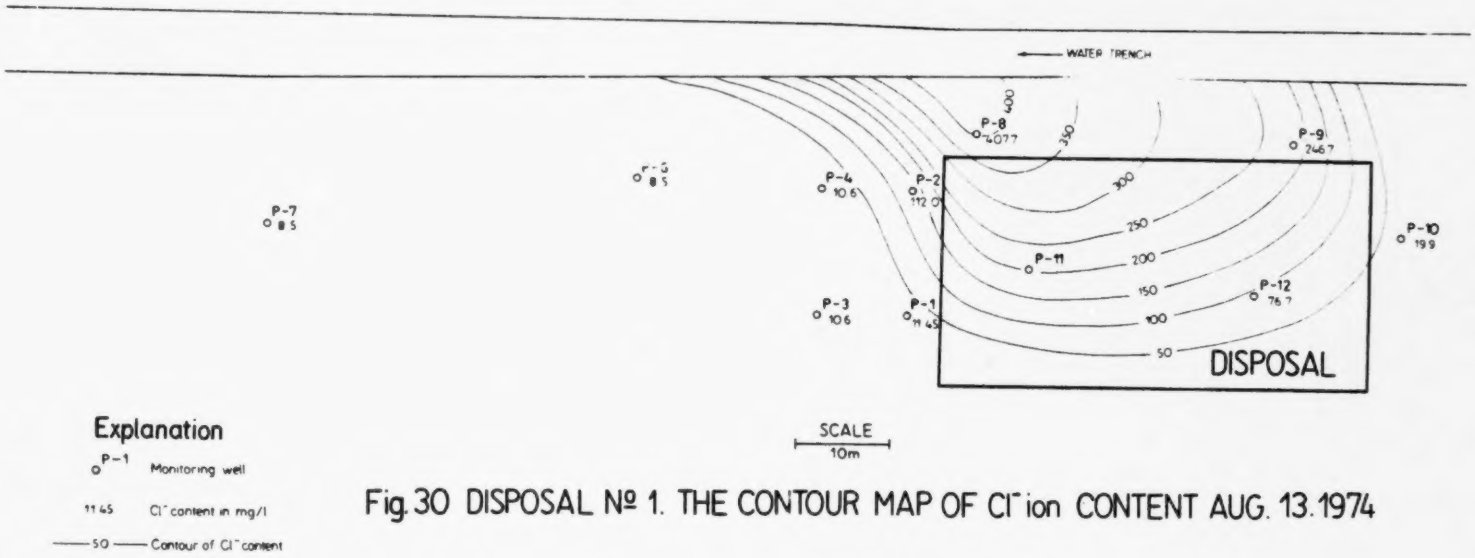


Fig. 30 DISPOSAL № 1. THE CONTOUR MAP OF Cl^- ion CONTENT AUG. 13. 1974

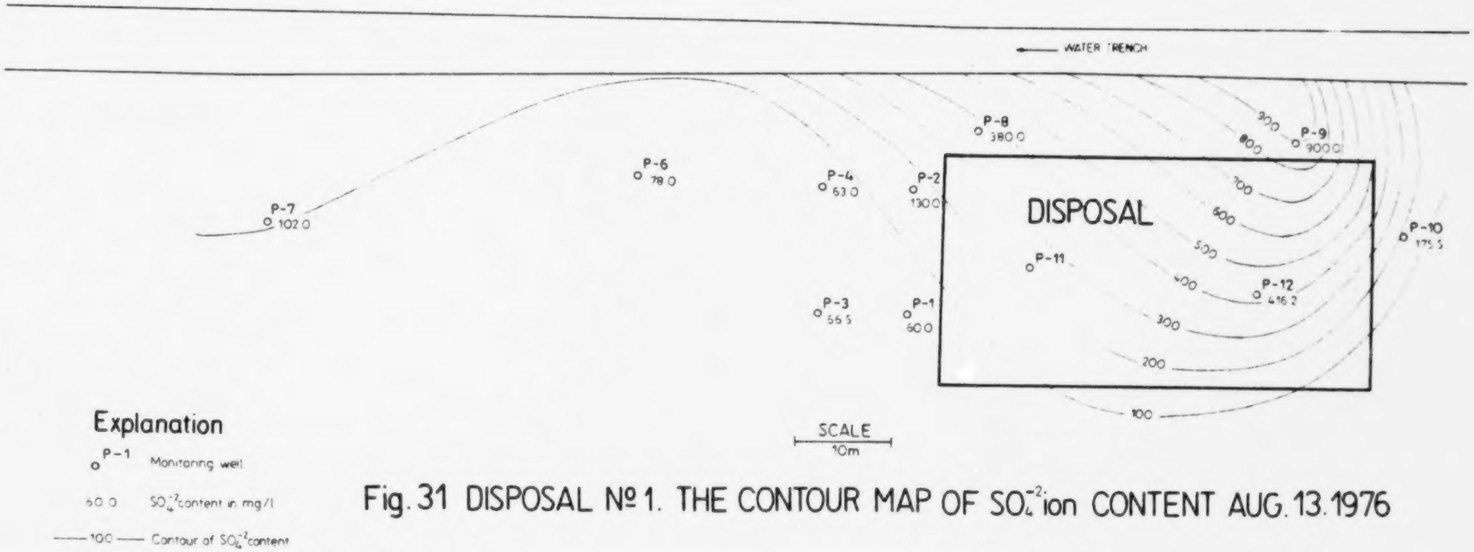


Fig. 31 DISPOSAL № 1. THE CONTOUR MAP OF SO_4^{-2} ion CONTENT AUG. 13. 1976

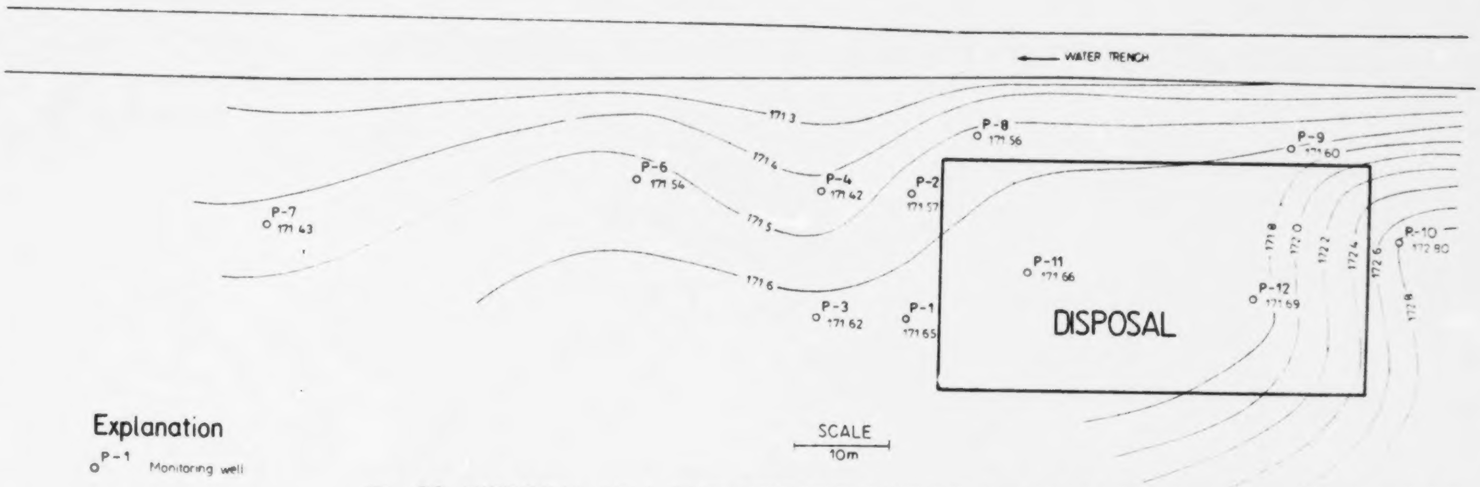


Fig. 32 DISPOSAL № 1. THE CCNTOUR MAP OF GROUNDWATER TABLE JULY 29.1975

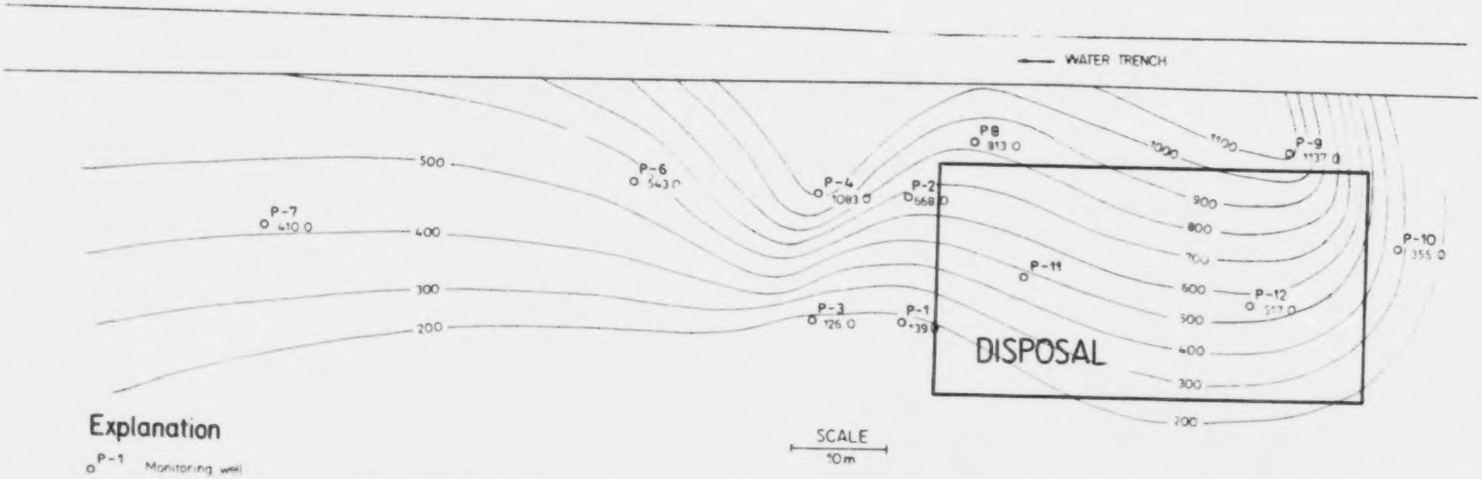


Fig. 37 DISPOSAL Nº 1. THE CONTOUR MAP OF TDS CONTENT APRIL 13.1976

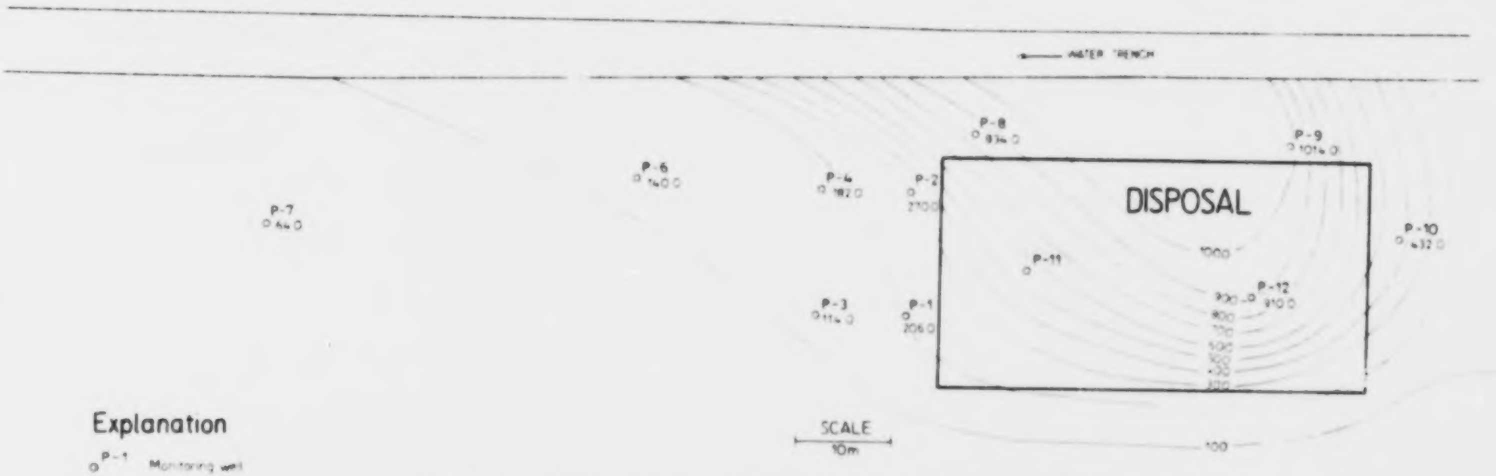


Fig. 33 DISPOSAL № 1. THE CONTOUR MAP OF TDS CONTENT JULY 29.1975

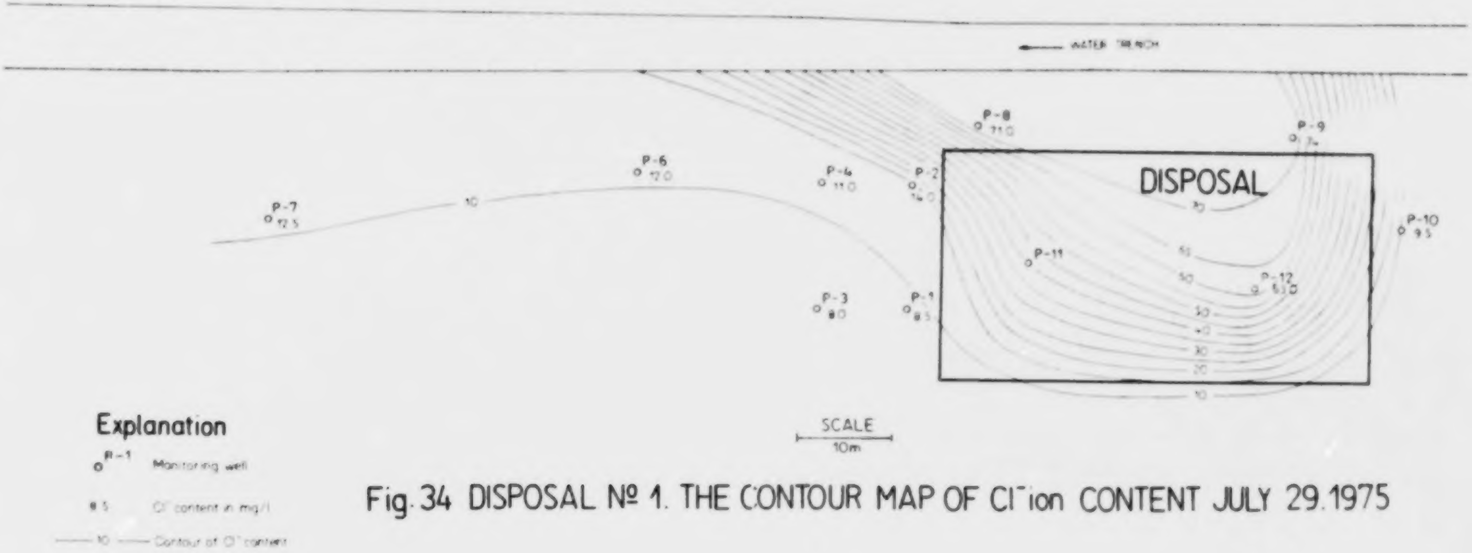


Fig. 34 DISPOSAL № 1. THE CONTOUR MAP OF Cl⁻ion CONTENT JULY 29.1975

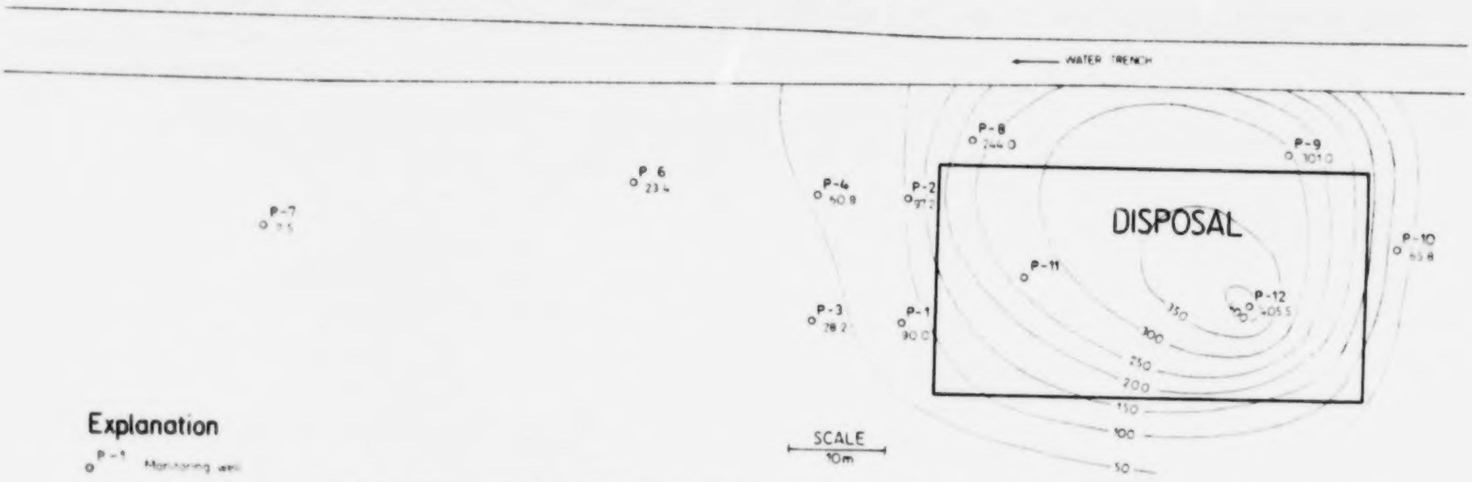


Fig. 35 DISPOSAL № 1. THE CONTOUR MAP OF SO_4^{-2} ion CONTENT JULY 29.1975

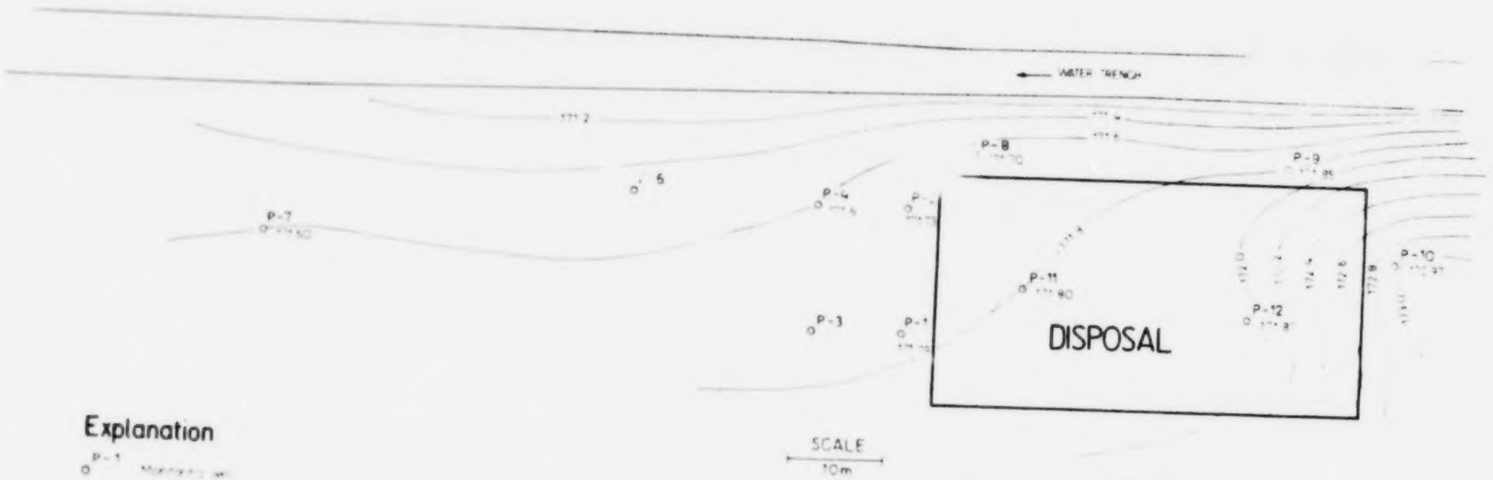


Fig. 36 DISPOSAL № 1. THE CONTOUR MAP OF GROUNDWATER TABLE APRIL 13 1976

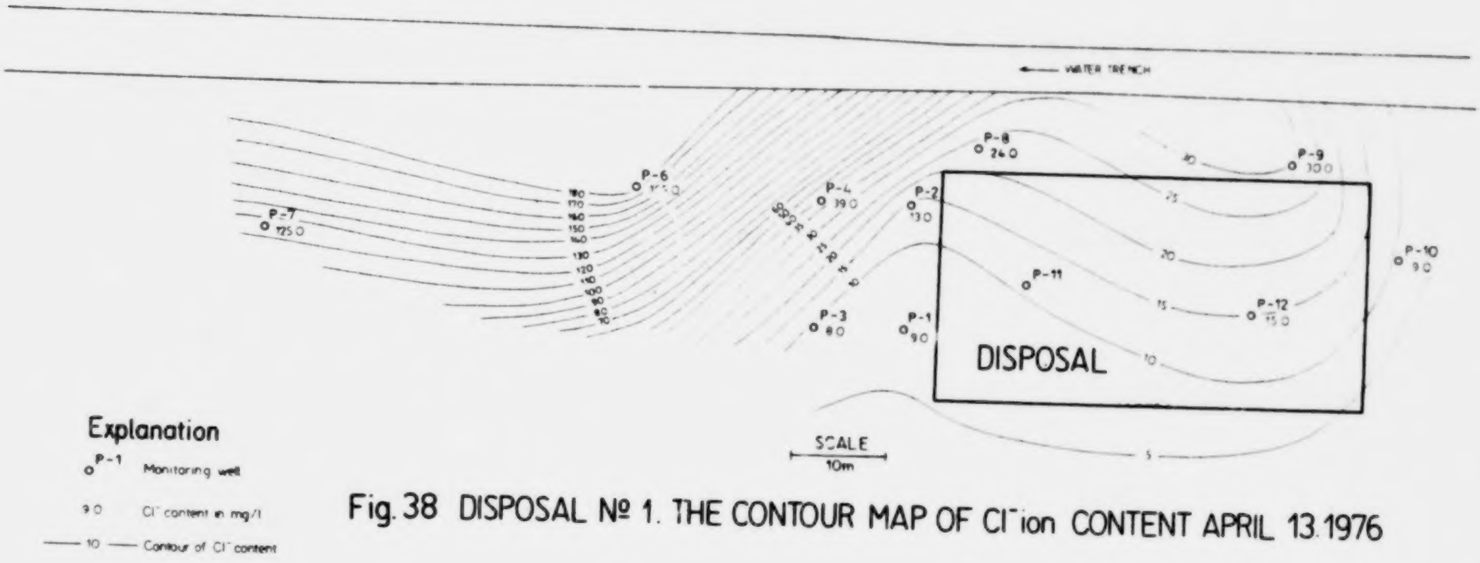


Fig. 38 DISPOSAL № 1. THE CONTOUR MAP OF Cl^- ion CONTENT APRIL 13.1976

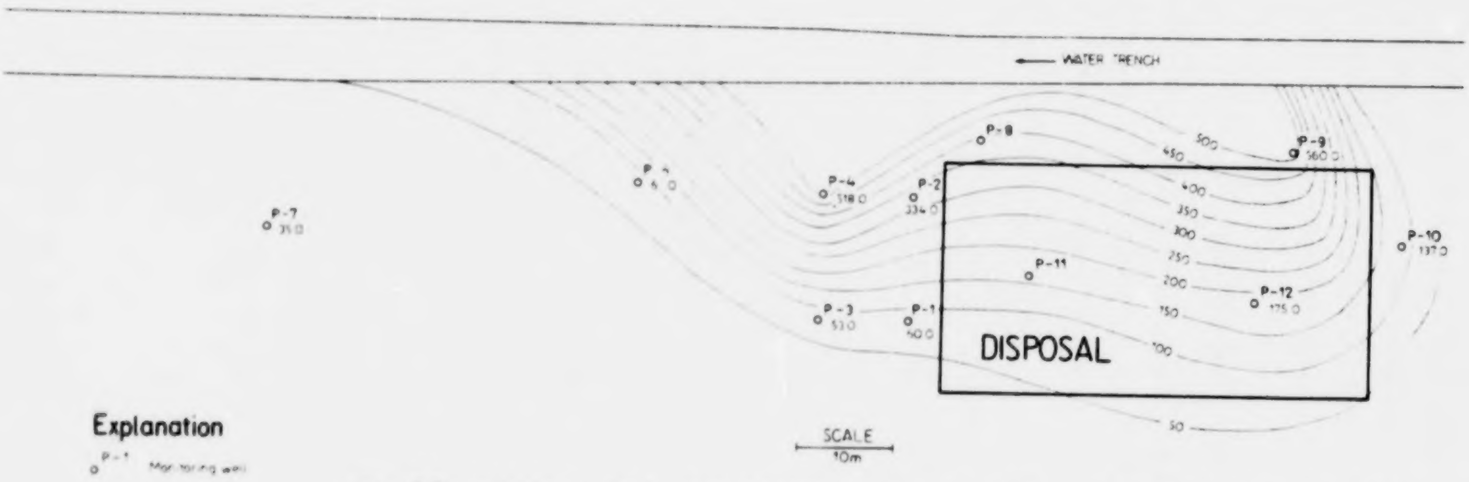


Fig. 39 DISPOSAL № 1. THE CONTOUR MAP OF SO_4^{-2} ion CONTENT APRIL 13. 1976

of the disposal are TDS then the sulphates and the chlorides. For these components a mass analysis was made regarding their quantities carried off by the ground waters out of the disposal, and speaking more exactly, to beyond that part of the aquifer which underlies directly the disposal.

Quantitative calculations were based on:

- the water table contour maps, the conductivity of the acquifer layer, and the map of concentration of the above named components in various time periods (e.g. the figs no. 24-39);
- chemical analyses of waters in wells chosen on the basis of the provided above materials;
- the formula for the mass of conveyed components is in a form of:

$$M = Q \cdot \Delta c \cdot t \qquad (6 - 1)$$

where:

Q - quantity of water flowing through a section under study in m^3/d

Δc - increase in component concentration in water departing the area of contact with disposal, as compared with pure ground water entering into contact with disposal, in g/m^3

t - time in days.

The quantity of water flowing through the computation section was determined with the formula:

$$Q = k.m.L.i \qquad (6 - 2)$$

where the:

k - coefficient of filtration in m/d
m - depth of the stream in m

L - width of the stream in m
i - hydraulic head.

It appeared from the analysis of available materials that the majority of pollutants leaved the region of disposal in the section between wells no. 8 and 9, small quantities also in a section between wells no. 8 and 2, and practically insignificant quantities (of under 1 %) in all other sectors.

The increment in concentration of particular components was computed in such a way, that an average value of component was taken from two monitoring wells typical for a given section and then from this value subtracted was content of component in question contained in initial ground water. Derived from two subsequent values an average value was considered as representative for a given time.

The results of calculations are presented in table below:

Quantities of leached pollutants from disposal by weight and in per cents

Table no. 6 - 7

Component	Direction of flow			Total kg	% in relation to deposited mass
	Section 8-9 kg	Section 2-8 kg	Remaining kg		
TDS	10 716	708	ca 70	11 494	0,76
Sulphates	7 138	404	ca 33	7 575	0,50
Chlorides	1 500	197	ca 24	1 721	0,11
Others	2 078	107	ca 13	2 198	0,15

As from the above mass computations appears leached from the disposal during $2\frac{1}{2}$ years of observations was 0,75 % of its mass, which constitutes about 80 % of soluble components contained in the stored mass. The quantitatively greatest pollutant were the sulphates, which made up about 70 % of the carried off mass; the quantity of leached sulphates constituted about 30 % of their total content in the disposal mass, calculated on the conversion from SO_3 to SO_4 component on about 20 500 kg.

ESTIMATION OF THE DEGREE OF POLLUTION BY PARTICULAR COMPONENTS IN THE LIGHT OF DRINKING WATER STANDARDS

The appraisal to what extent the particular components may threaten the quality of ground water, undergoingthe influence of disposal, were arrived at through comparisons made of allowable contents of the components for waters of the I, II and III class of purity (according to the Polish Standards) and USA and WHO drinking water standards, with the actual contents of the same components in the laboratory leachates and in the ground waters of the disposal environment.

As from the table no. 6 - 8 appears, in the light of obligatory regulations the most unequivocal threat to the quality of ground waters may manifest the sulphates, as their concentration in ground waters was exceeding four times the concentration allowable by Polish Standards and US Standards making such waters practically not fit for use. The second important component exceeding permissible standards are TDS the quantity of which is exceeding the allowable amounts also 4 times. The third in succession component clearly exceeding the standards are the chlorides, the content of which in relation to the requirements was two times greater. So far as the remaining components are concerned one can say, that:

pH of in polluted ground water almost meets standards
Fe contents in polluted ground water exceeds standards
Mn " " " " " "
CN " " " " meets standards
phenols " " " " exceeds standards
Pb " " " " " "
Hg " " " " meets standards
Cu " " " " meets standards

Comparative specification of potential danger to ground water

Table no. 6 - 8

Component	Unit	Allowable maximal content in waters					Content in laboratory leachate	Maximal content found in ground water
		Polish Standards			USA	WHO		
		I Cl.	II Cl.	III Cl.				
pH	pH	6,5–8,0	6,5–9,0	6,0–9,0	6,0–8,5		8,5–12,0	6,8–8,7
TDS	mg/dm^3	500	1000	1200	500	500	3000	2100
Cl	– " –	250	300	400	250	200	680	600
SO_4	– " –	150	200	250	250	200	2000	900
Fe	– " –	1,0	1,5	2,0	0,3	0,3	23,9	1,3
Mn	– " –	0,1	0,3	0,8	0,05	0,1	–	0,9
PO_4	– " –	0,2	0,5	1,0	–	–	5	0,07
CN	– " –	0,01	0,02	0,05	0,012	0,01	0,032	0,02
phenols	– " –	0,005	0,02	0,05	0,001	0,001	0,02–1,0	0,025
Pb	– " –	0,1	0,1	0,1	0,005	0,02	0,08–0,5	0,05
Hg	– " –	0,001	0,005	0,01	0,001	0,001	0,006	0,0009
Cu	– " –	0,01	0,1	0,2	1,0	1,0	0,034–0,2	0,04
Zn	– " –	0,01	0,1	0,2	5,0	5,0	0,13–4,0	0,14
Cd	– " –	0,005	0,03	0,1	0,01	0,05	0,02–0,05	0,012
Cr	– " –	0,5	0,5	0,5	0,05	0,05	0,065	0,025
B	– " –	1,0	1,0	1,0	1,0	1,0	0,4–7,0	2,1
As	– " –	1,0	1,0	1,0	0,01	0,2	0,1	0,032
Mo	– " –	–	–	–	0,05	–	0,22	0,15
Sr	– " –	–	–	–	0,1	–	1,5	0,5
COD MnO_2	– " –	10	20	30	7,5	10	8,0	rank 2–3
COD Cr	– " –	40	60	100	50	40	29,9	–
BOD_5	– " –	6	5	4	2,5	5,0	–	3,5

Zn contents in polluted ground water almost meets standards
Cd " " " " " exceeds standards
Cr " " " " " meets standards
B " " " " " exceeds standards
As " " " " " " "
Mo " " " " " " "
Sr " " " " " " "

SUMMARY OF RESEARCH CARRIED OUT ON DISPOSAL NO. 1

The results acquired in the research performed on the disposal no. 1 allowed of their critical assessment and drawing of conclusions of methodical and of substantial character. In the scope of methodology they allowed to draw conclusions and to propose the classification of waste material and of its laboratory examination, the localization of monitoring wells, the water sampling and the hydrogeological surveys. In the competence of substantial conclusions they allowed the determinations of quantities of particular components, passing from the disposal to ground waters and of danger which they may pose to the ground waters quality. It was successful to some extent to draw conclusions regarding the directions and the velocities of pollutant migration, and also regarding the masses of leached components.

Methodological conclusions

1. The waste material under study can not be considered as uniform, as it differentiates clearly and one can distinguish the following groups:

   Group I - Coal mining refuse

   Sub-group A) Dry refuse - included into it can be material coming from ripping, from preparatory work and from dry separation.

Sub-group B) Wet refuse - included here is material coming from coal washeries and from floatation processes,

Group II - power plant wastes

Sub-group A) Fly ashes
Sub-group B) Slags (bottom ashes).

2. The laboratory investigations of wastes allowed to appraise the kind and the maximal practical concentration of basic leachable components. With great caution must be treated their results for drawing conclusions regarding the total masses of possible to leach components, as laboratory leaching did not take into account to a sufficient degree the time factor.

3. The observation system afforded an answer to basic questions put at the research program.

4. No essential influence of prior pumping out of monitoring wells before sampling on the result of water analysis was observed.

5. The most appropriate method of water sampling appears to be a prior scooping of water from each well in quantity about double the volume of the well to remove the stagnating in well water, without infringing on the natural regime of ground waters.

6. The adopted in investigations frequency of water sampling every three weeks must be recognized as sufficing to determine the gist of the occurrence, and of all its components, and not only for a random confirmation of the fact of pollution. A more rare water sampling may lead to substantial errors.

7. Very important is to have at one´s disposal exact comparison data concerning pure ground waters to distinguish the pollution not connected with the disposal presence - because such appearances could point to the disposal as their source.

Substantial conclusions

1. Dry disposal of wastes coming from mines of bituminous coal (70 %), and of fly ashes and slags from power plants fired with coal (30 %), localized above the ground water table, and only periodically immersed in its bottom part, was affecting in a clear way the pollution of ground waters.

2. Clear signs of pollution in the zone of disposal appeared in the seventh month after the storage of material, although initial signs in a shape of gradual increase in pollution in direct subsoil of the disposal were occurring right from the moment of wastes storing.

3. Observed was clear dependence between precipitation values and the increase in pollution. This occurrence was very pronounced in initial stage of observations, later this blurred a little, and this can be explained by subsequent superimposition of particular waves of pollution.

4. The main body of pollutants was displacing itself with a velocity approaching velocity determined by classical methods for a water flow in aquifer.

5. No distinct quantities of pollutions was observed outside the main direction of ground water stream flow, i.e. in the directions where although does exist a gradient in the water table but is much smaller. This would signify, that the pollutants are carried chiefly in the main stream of the ground waters' flow.

6. The reach of dispersive displacement of pollutants of considerable concentration was very small. From practical view point, when the disposal is situated in conditions of a distinct hydraulic gradient such a displacement may be disregarded. The attention must be drawn however to a very different mobility of particular ions, and their ability to different moving away from the main direction of stream carrying the pollutants.

7. The presence of a disposal 2,5 m high induced in the underlying it aquifer clear qualitative changes, whereby these pollutions were most conspicuous direct down the stream of ground waters, smaller in the direct subsoil of the disposal, and only very small in the zones of lesser gradients of the ground water table.

8. Taking into account particular parameters and components of waters polluted by the disposal, one may state that disposal 2,5 m thick in ground waters of drinking quality did effect following changes:

- increase in weight by volume of underground waters by about 0,2 %

- increase in waters´ conductivity about 10-fold, whereto for quick orientational designations multiply the conductivity value in μ/s by coefficient 0,7 is sufficient to obtain the sum of total dissolved substances in mg/l

- increase in total of dissolved substances about 10-fold, with a clear dependence particularly during the first period on the amounts of precipitation

- increase in the content of ion Cl to 40 times
- " " " " SO_4 to 10 times
- " " " " Na to 100 times
- " " " " K to 20 times
- " " " " Ca to 6 times
- " " " " Mg to 2 times
- " " " " NH_4 to 4 times
- " " " " PO_4 to 8 times
- " " " " CN to 10 times
- " " " " phenols to 2 times (if any)
- " " " " ion Cd to 3 times
- " " " " Sr to 5 times
- " " " " Cu to 6 times

- increase in the content of ion Pb to 2 times (if any)
- increase in the content of ion Mo to 15 times
- " " " " B to 25 times.

It appears however, that the existence of the disposal did not effect any increases in the Fe, Mn, Al, Cr content nor a clear change in the pH reaction.
Due to non-uniformity of results difficult is to answer to what extent the disposal effected an increase in ground waters in the Zn, Pb and Hg. This influence cannot be excluded and it may express itself with values within limits of two to three times.

9. During the two and half years of duration of disposal with a volume 1500 m^3, leached out from it was about 11.500 kg of pollutants (0,75 % of its mass), which makes about 80 % of soluble components contained in the stored material.

10. The main pollutants were sulphates, then the TDS, and among heavy metals the boron, molibdenum and copper.

11. Very different presents itself comparison of the quantity of particular components contained in disposal, that pass into the ground waters. These quantities are showing a wide span, and an extreme instance may here be comparison of sodium and potassium. If in the case of sodium its maximal values in ground waters as opposed to acquired ones in laboratory conditions amounted to nearly 85 %, then in the case of potasium these were coming only to 15 %. Very different is also the mobility of particular ions, and different the trend to a dispersive displacement.

12. In the light of the above a generalizing conclusion prompts itself, that accurate forecasting of pollution increase in ground waters as effected by the disposal cannot be performed in a universal way with the application of the same criteria for all polluting components. Entirely different can be both the quantity and the range of pollution by different components.

SECTION 7

RESULT OF TESTS ON THE DISPOSAL NO. 2

LOCATION, CLIMATIC AND HYDROGEOLOGICAL CONDITIONS

The second test disposal is located at a distance 200 km South West from Wrocław. It is an old open-pit mine of stowing sand exploited in the Sixties for the needs of deep coal mining. This open pit has a capacity of about 800.000 m^3 and decided was to include it, into the research in place of a previously planned small disposal, in the framework of this project, of capacity 100 m^3. For the occasion arose, as in this abandoned for 6 years open pit commenced at the beginning of 1975 a systematic storage of gob coming from situated in a vicinity deep coal mines.

The disposal is situated on an area of a morphological elevation, where the terrain surface is within limits + 275 m to + 280 m above s.l. and declines in various degrees toward all directions from the disposal. To the East at a distance of 1 km the elevation of terrain comes to about 255 m above s.l. and to the North these values occur already at distance of about 300 m. In the Western and Southern directions the terrain declines more gently to ordinates + 265 to + 275 m above sea level. The surface of the terrain cover meadows and arable land and in the direction about 1 km East the forests occur. The average long term precipitation value for this area amounts to 731 mm, and a maximal storm precipitation that was ever recorded within one hour was 70.3 mm. An essential element of carried out investigations especially on account of the disposal being positioned above the ground water table (which will be discussed further on)

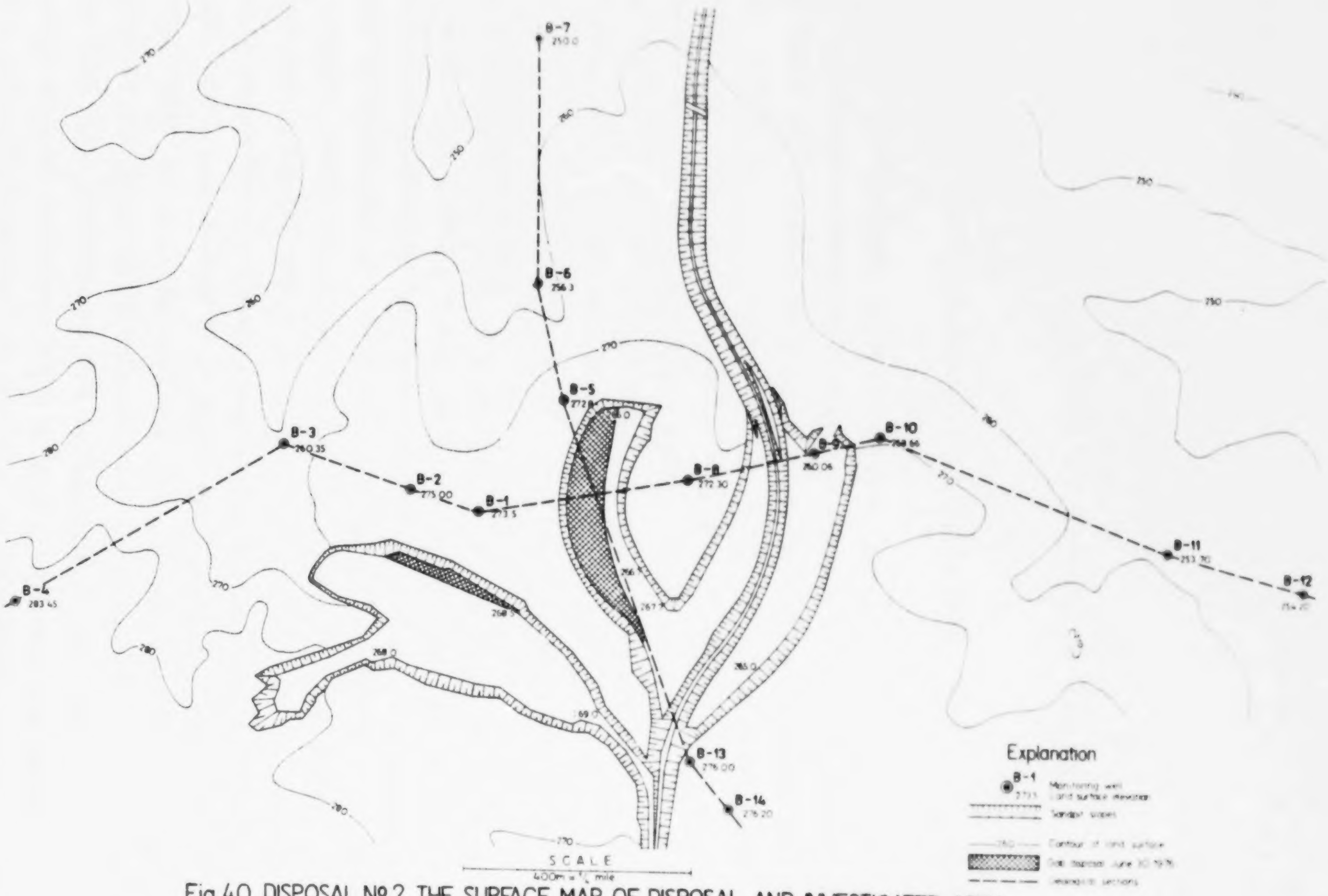


Fig.40 DISPOSAL № 2. THE SURFACE MAP OF DISPOSAL AND INVESTIGATED AREA

DISPOSAL NO. 2

THE AVERAGE DAILY TEMPERATURES

Table 7–1

Day	1975												1976							
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII
1	1,2	1,9	3,0	1,8	10,1	7,3	12,4	18,2	19,6	19,4	3,7	4,6	1,7	-8,4	5,2	11,8	7,2	10,7	20,8	14,8
2	3,0	3,6	5,2	4,5	11,2	6,6	19,8	16,4	20,1	15,8	4,6	5,8	2,0	-7,0	3,4	12,4	9,6	11,0	19,7	14,1
3	3,4	0,4	7,4	5,8	10,3	11,7	20,2	16,7	20,0	15,4	7,7	4,4	3,3	-8,5	0,5	15,2	13,2	11,3	20,6	14,5
4	2,1	-2,5	6,2	9,2	8,8	12,8	20,0	18,5	19,5	13,3	7,6	4,4	-0,5	-2,8	-2,7	12,5	14,6	9,6	22,0	14,3
5	3,8	-3,3	9,1	13,3	11,0	11,3	20,4	16,4	17,7	10,0	7,6	2,9	-2,8	-1,6	-3,6	12,4	14,0	13,0	18,6	14,0
6	6,1	-2,9	7,3	13,5	14,8	10,8	20,3	19,1	14,8	12,3	6,9	4,1	0,7	-5,6	-3,4	12,4	,13,8	14,2	15,6	14,4
7	5,8	-2,4	7,8	8,1	18,2	12,6	19,6	20,6	15,1	11,0	6,5	0,9	-2,1	-5,5	-4,6	7,0	14,4	17,2	17,0	13,8
8	0,3	-2,2	8,0	7,5	18,1	12,2	20,0	21,2	13,0	8,5	7,0	2,4	1,2	-7,2	-3,1	4,0	14,1	18,1	17,0	14,4
9	-1,4	-3,6	9,8	7,2	14,7	14,8	21,4	22,0	11,4	6,7	4,0	2,6	2,7	-4,6	-1,5	4,0	16,4	14,9	16,0	15,6
10	1,6	0,1	11,5	6,2	14,6	16,2	21,4	20,7	15,1	5,0	2,6	1,5	2,6	-3,4	-3,0	3,8	17,1	12,7	14,1	17,8
11	4,4	1,7	10,2	3,2	14,7	17,2	20,7	21,6	16,0	4,0	0,8	-0,4	3,5	-2,1	-4,8	4,8	17,4	14,4	17,4	17,5
12	5,5	4,0	8,6	3,1	15,8	18,7	21,1	21,0	13,9	3,0	0,9	-1,8	6,1	-2,8	-3,9	6,4	16,7	15,8	20,0	17,0
13	5,2	3,6	6,2	4,2	12,1	20,2	20,4	15,6	11,8	6,9	1,7	0,8	2,6	-4,2	-1,2	6,5	14,7	16,4	21,3	16,9
14	5,0	3,4	4,5	4,6	18,1	18,3	22,9	14,6	14,6	10,0	3,5	-0,1	-0,3	-1,4	0,3	9,6	7,6	14,2	20,4	14,2
15	5,1	-1,7	6.6	9,8	19,4	21,6	24,0	16,8	17,4	4,8	3,0	-3,4	-0,4	1,1	1,4	7,4	9,3	16,2	19,4	15,6
16	5,0	-5,5	7,0	9,5	16,1	21,5	23,7	19,4	18,6	9,5	3,1	-2,5	-5,7	-0,2	3,8	9,8	13,2	11,8	20,7	16,2
17	4,1	-5,9	1,6	5,3	18,2	14,3	20,0	20,1	19,4	8,7	2,2	0,1	-2,0	-1,7	2,6	10,7	14,4	11,9	22,6	17,5
18	5,1	-1,1	1,4	5,2	18,3	13,8	18,4	17,7	20,2	7,8	7,9	-5,3	-3,8	-1,6	0,1	11,4	16,2	17,2	25,0	14,8
19	6,0	0,1	5,2	6,4	20,4	15,5	18,3	16,5	18,0	8,6	4,9	-11,9	1,0	1,3	-0,1	12,6	16,2	20,0	25,6	14,3
20	5,2	0,1	6,2	7,2	15,9	19,1	15,6	17,2	16,8	6,8	3,2	-3,2	2,0	2,0	-3,9	11,2	16,5	21,0	24,5	14,6
21	3,6	-0,5	-0,3	7,7	15,2	19,4	15,3	17,7	16,2	8,0	0,4	-1,6	3,2	1,2	.-5,3	8,0	14,9	20,1	22,7	13,2
22	3,2	-5,0	-0,2	7,8	12,9	20,7	18,0	18,7	15,8	9,8	-0,4	2,3	1,7	0,2	-4,1	3,0	10,1	18,8	16,9	13,0
23	2,8	-2,4	1,5	8,2	9,4	20,5	20,5	19,1	14,7	10,6	-2,0	2,4	3,2	0,0	-4,1	2,0	12,1	18,4	15,5	13,4
24	4,8	1,9	1,0	9,9	11,2	21,8	20,7	16,4	17,4	8,0	-3,0	2,0	-0,4	-1,2	-2,6	6,3	10,4	18,5	14,8	14,0
25	4,0	-0,4	2,2	6,0	11,5	19,6	13,5	17,8	16,4	3,8	-8,4	1,7	-3,9	-0,4	1,4	6,3	15,4	19,7	14,4	17,0
26	4,3	-1,6	1,5	5,8	11,4	18,7	12,6	16,2	18,2	3,2	-0,8	0,1	-4,4	4,2	5,0	5,6	16,6	20,0	18,2	18,6
27	1,4	-0,4	2,1	7,7	13,5	19,8	14,3	17,2	14,9	5,4	-5,8	4,0	-7,0	5,6	5,1	6,9	12,4	21,8	17,6	19,2
28	0,2	0,8	7,4	9,0	16,0	16,7	14,2	16,0	18,8	4,8	1,4	2,9	-7,5	4,6	4,8	2,1	11,8	22,5	18,2	16,6
29	1,2		4,1	13,0	17,2	12,9	20,2	17,2	19,2	6,4	5,0	2,7	-8,3	5,7	8,8	1,6	11,9	22,6	15,2	19,5
30	1,4		2,8	12,6	15,2	13,2	18,6	18,1	18,8	8,1	5,2	-0,7	-7,6		8,9	4,3	13,4	21,2	17,0	19,4
31	2,2		1,1		10,6		18,7	19,0		5,1		0,1	-8,0		8,2		11,8		19,5	18,9
Monthly average	3,4	-0,7	- 5,0	7,4	14,4	16,0	18,9	18,2	16,8	8,4	2,3	0,7	-0,6	-1,5	0,1	7,8	13,5	16,5	19,0	15,8

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DISPOSAL NO. 2

THE DAILY AND MONTHLY SUMS OF PRECIPITATIONS
(in mm)

Table 7-2

Day	1 9 7 5												1 9 7 6							
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII
1	28,3	2,3	.	.	.	5,9	24,9	6,1	.	.	.	.	1,8	.	0,6	.	.	0,0	.	1,1
2	.	4,5	.	.	.	2,6	.	0,2	0,0	.	.	.	.	.	0,0	.	.	5,9	.	.
3	.	.	.	.	0,0	.	.	3,0	0,0	2,0	0,6	0,0	7,5	.	.	.	1,0	.	.	6,8
4	3,2	.	.	.	0,0	.	.	0,2	.	.	0,1	0,0	1,8	.	0,5	.	0,0	.	.	2,7
5	3,5	.	0,5	1,0	.	.	.	8,3	68,5	5,9	.	2,1	0,5	.	0,7	0,6	.	.	.	0,2
6	0,0	.	1,0	0,0	.	0,0	.	.	.	1,1	0,1	5,0	.	.	0,3	.	.	.	.	2,0
7	0,0	2,5	.	7,0	.	5,7	.	2,2	0,0	5,8	0,8	.	.	.	.	.	.	.	1,9	20,1
8	1,2	.	.	.	1,4	10,3	.	.	.	2,3	.	0,2	.	.	.	2,6	.	.	0,3	0,6
9	.	.	.	.	1,2	1,4	.	.	.	4,0	.	.	2,3	.	.	.	.	.	22,6	.
10	.	.	.	18,0	.	.	12,4	0,0	.	0,2	.	0,0	9,8	.	.	.	.	.	8.0	.
11	.	.	1,3	0,0	.	.	.	.	0,6	0,0	0,0	.	4,8	1,6	.	.	.	.	.	0,0
12	.	.	9,8	0,5	.	.	0,4	0,4	18,0	0,4	.	.	8,4	0,5	.	.	.	.	3,5	.
13	0,0	0,7	5,5	0,0	.	0,3	.	.	0,6	0,8	.	0,0	6,0	.	.	1,8	19,5	2,8	.	.
14	.	1,1	0,0	2,8	.	.	.	.	.	33,2	15,8	.	12,2	.	.	.	13,2	.	1,0	1,8
15	.	.	.	5,6	.	.	.	.	.	10,4	2,6	.	1,2	0,5	0,0	1,5	.	14,4	2,8	.
16	.	.	1,5	4,7	.	10,5	.	26,5	.	2,8	.	.	1,5	.	0,0	1,4	.	4,9	.	.
17	.	.	14,6	7,9	.	1,0	.	8,8	.	0,1	0,0	11,1	1,7	.	2,1	.	.	7,5	.	.
18	.	0,4	.	0,3	.	11,4	0,4	62,5	.	22,1	10,6	.	5,5	.	2,0	.	.	.	.	.
19	.	16,1	3,7	.	2,8	1,0	4,5	1,0	.	5,5	3,1	0,0	1,1	.	11,4	.	.	.	0,3	3,1
20	.	.	1,0	.	.	21,4	35,0	.	.	5,5	5,9	.	1,5	.	1,2	.	0,0	3,5	.	6,1
21	.	.	.	.	0,6	5,2	8,0	.	.	8,8	1,7	0,2	1,8	.	4,6	1,3	19,0	.	10,2	1,7
22	.	.	.	.	0,0	.	.	.	.	.	2,9	1,8	6,2	.	0,0	5,8	26,5	.	12,4	.
23	.	.	.	.	0,5	1,6	.	.	.	.	.	.	6,3	.	.	2,3	1,6	.	23,4	.
24	0,0	.	.	2,0	.	4,1	17,0	0,0	.	.	.	0,5	2,9	.	.	2,6	0,0	.	8,3	.
25	1,7	.	0,4	0,6	25,1	9,0	14,4	8,4	.	.	.	4,2	0,0	.	0,0	1,0	.	.	0,8	.
26	0,0	.	5,5	0,0	0,8	.	4,5	20,0	8,5	.	.	11,5	.	0,6	4,8	1,7	15,2	.	3,7	.
27	.	.	0,6	.	.	.	1,8	.	.	.	.	3,2	.	0,4	5,4	.	5,6	.	2,3	.
28	0,3	.	15,9	.	.	24,4	1,3	.	0,0	.	1,4	.	1,0	.	.	0,0	2,6	.	.	.
29	0,5	.	.	.	1,3	.	.	1,8	.	.	.	.	.	.	.	.	.	.	.	.
30	.	.	24,1	.	7,1	6,0	16,0	2,6	.	.	.	.	.	.	.	.	8,6	.	.	.
31	.		1,0		4,8		.	.		.		.	.		.		16,6	.	12,6	1,9
Monthly Sum	38,7	27,6	86,4	50,4	45,6	121,8	140,6	152,0	96,2	110,9	45,6	42,8	85,8	3,6	33,6	22,6	137,4	39,0	114,1	48,1

are the climatic conditions obtaining during the tests´ performance.

Average daily air temperatures measured at a meteorological station situated about 5 km away during the period from Sept. 1, 1974 to June 30, 1976 are shown on the table no. 7 - 1.

As from this table appears the warmest month was July 1975, (average temperature was 18,9°C, and the highest daily average 24°C) the coldest February 1976 (average temperature - 1.5°C, and the lowest daily average was - 8.4°C).

The above temperature values should be useful for comparisons of conditions in which were carried out investigations, with conditions of an optional disposal for which conclusions could be drawn on the basis of these studies.

Particularly this is important for cases, where these values may have influence on the evaluation of infiltration coefficient dependent on evaporation.

Values of essential significance however are the values of precipitation, which are the source of water for the considered aquifer, and also are the source for leaching and transportation of the pollutants. The table no. 7 -2 illustrates daily and monthly precipitations.

From the above table the dryest month was February 1976 (with the sum of precipitations 152.0 mm).

Maximal daily precipitation amounted to 62.5 mm and took place on August 18, 1975. In relation to long term averages, draws the attention higher by about 15 % sums of annual precipitation.

Hydrogeological conditions of the disposal are illustrated on the enclosed maps and cross - sections. In the geological structure of area under study there are formations of Carboniferous, Tertiary and the Quaternary Periods.

The Carboniferous period is represented by tectonicly disturbed formations of Upper Carbon formed in the shape of shale and sandstone with coal deposits. This series with thickness of few thousand meters was not ascertained on the investigated area with direct tests as it occurs at depth over 100 m. Layers of Carboniferous characterized with irregular water bearing capacity dependent on the lithology and on fissures. The rocks and waters of this horizon are characterized by a considerable salinization. The carboniferous aquifer has no greater significance from the considered point of view on account of great depth of occurrence and lack of direct contacts with the disposal, but also cannot be a source of supply with drinking water for the region.

Tertiary formation occurring directly on the roof of the Carboniferous is formed mainly in the shape of clays containing lenses of sand and gypsum bands. Thickness of this series changes within 50-150 m limits. The tertiary aquifer formations are only sand lenses with small horizontal and vertical spreading. So this aquifer has a discontinuous character and waters compose closed reservoirs with static resources, and have no contact with the disposal.

Quaternary - on the impermeable tertiary subsoil were posed quaternary formations, within of which is located our disposal. They form a sandy - clayey series of 10 - 40 m thickness (on average 20 - 30 m). The clays prevail in the floor and the roof parts of the Quaternary, and sands form the center.

Thickness of the sands within the reach of the old open pit changes from 3 to 20 m, and in its, bottom part, where the sands were exploited, from 0 - 8 m. Within the range of the sands, lenses of silts and gravels appear of a small thickness, with local spreading.

The permeability of sands was determined with laboratory methods for all layers differing in lithological respect. For the wells situated in a direct neighbourhood of the disposal we determined the permeability of all permeable layers from the terrain surface down to the floor, and

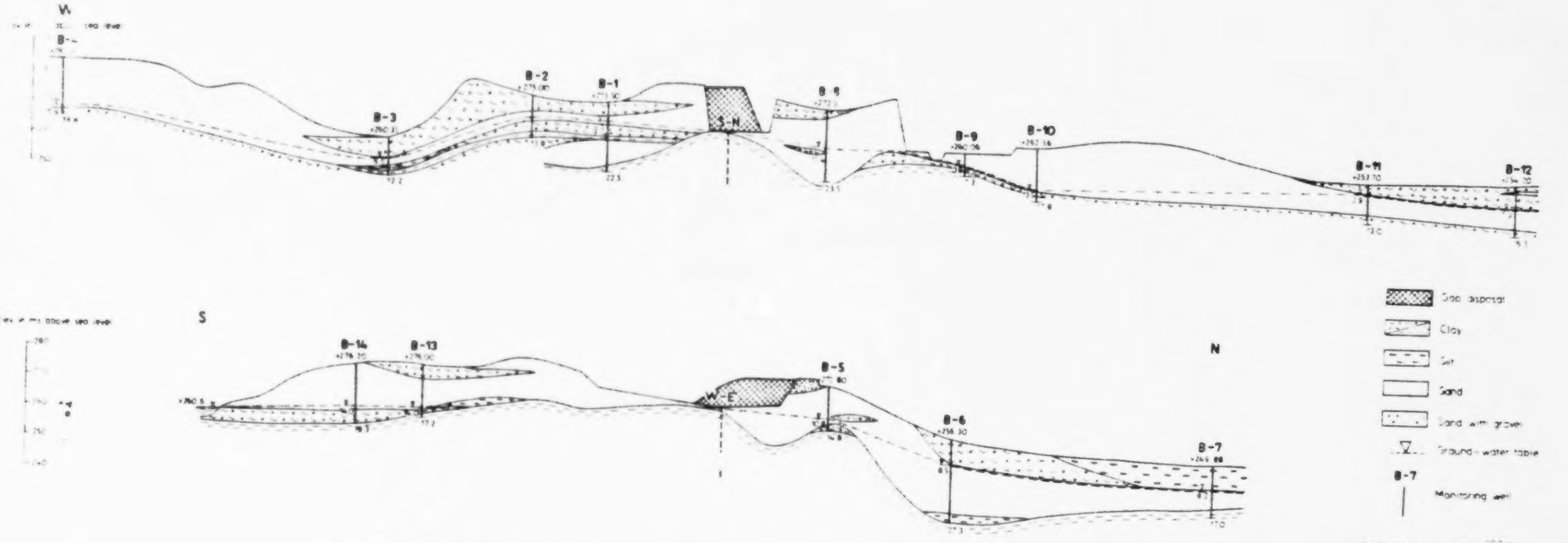

Fig.41 DISPOSAL № 2. HYDROGEOLOGICAL SECTIONS

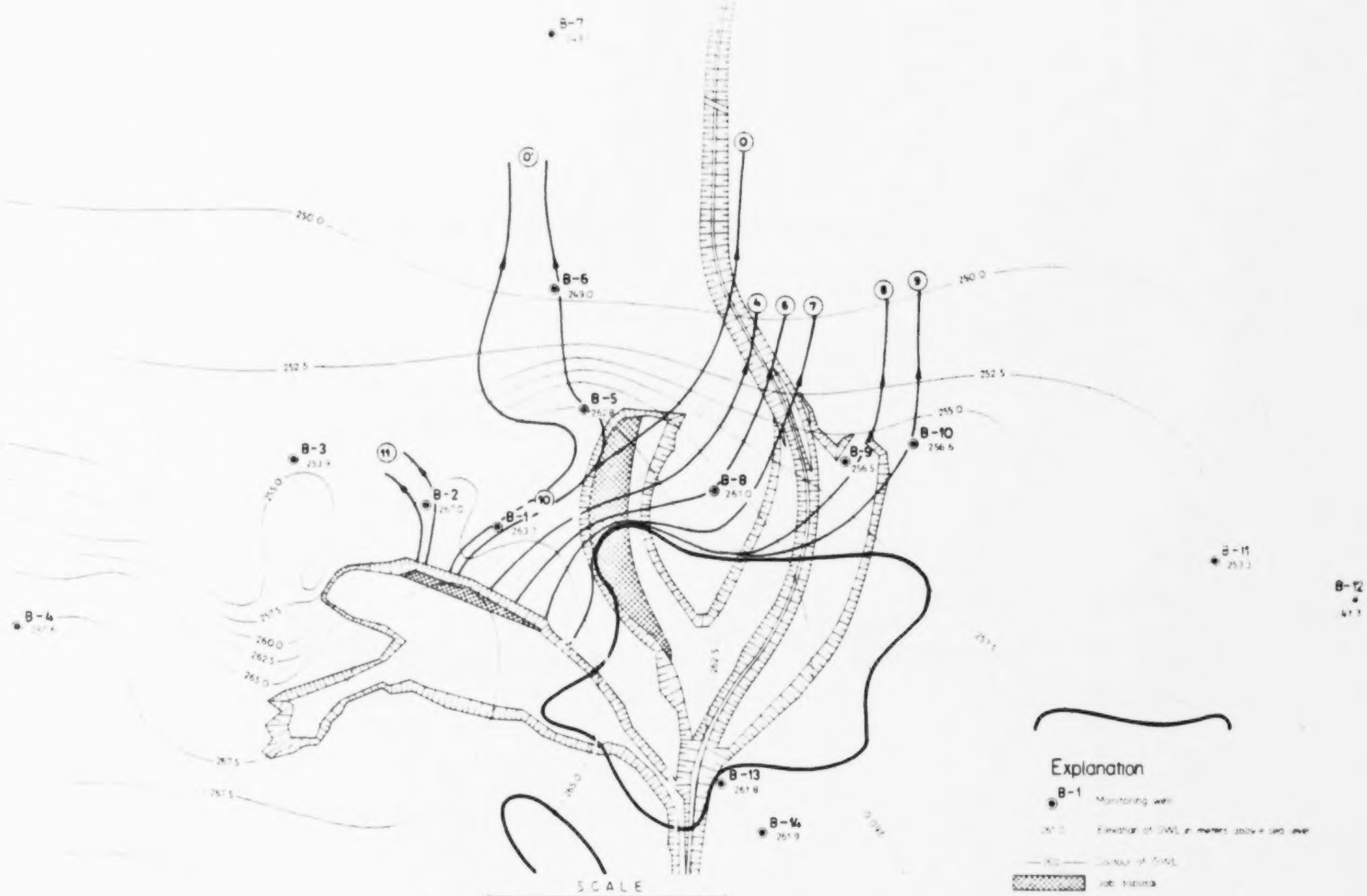

Fig. 42 DISPOSAL № 2 THE CONTOUR MAP OF GROUND WATER TABLE

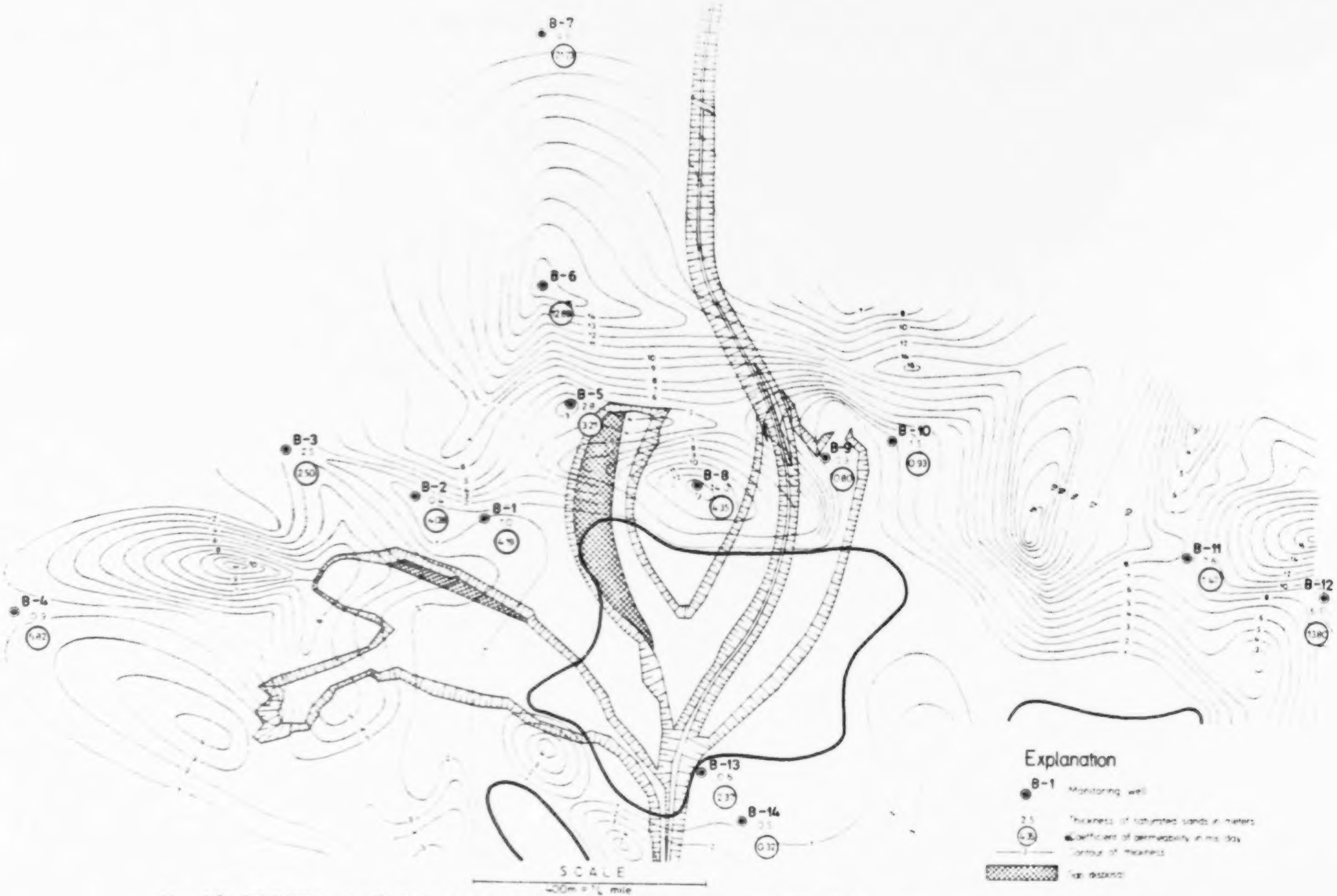

Fig 43 DISPOSAL № 2. THE CONTOUR MAP OF SATURATED AQUIFER THICKNESS AND PERMEABILITY

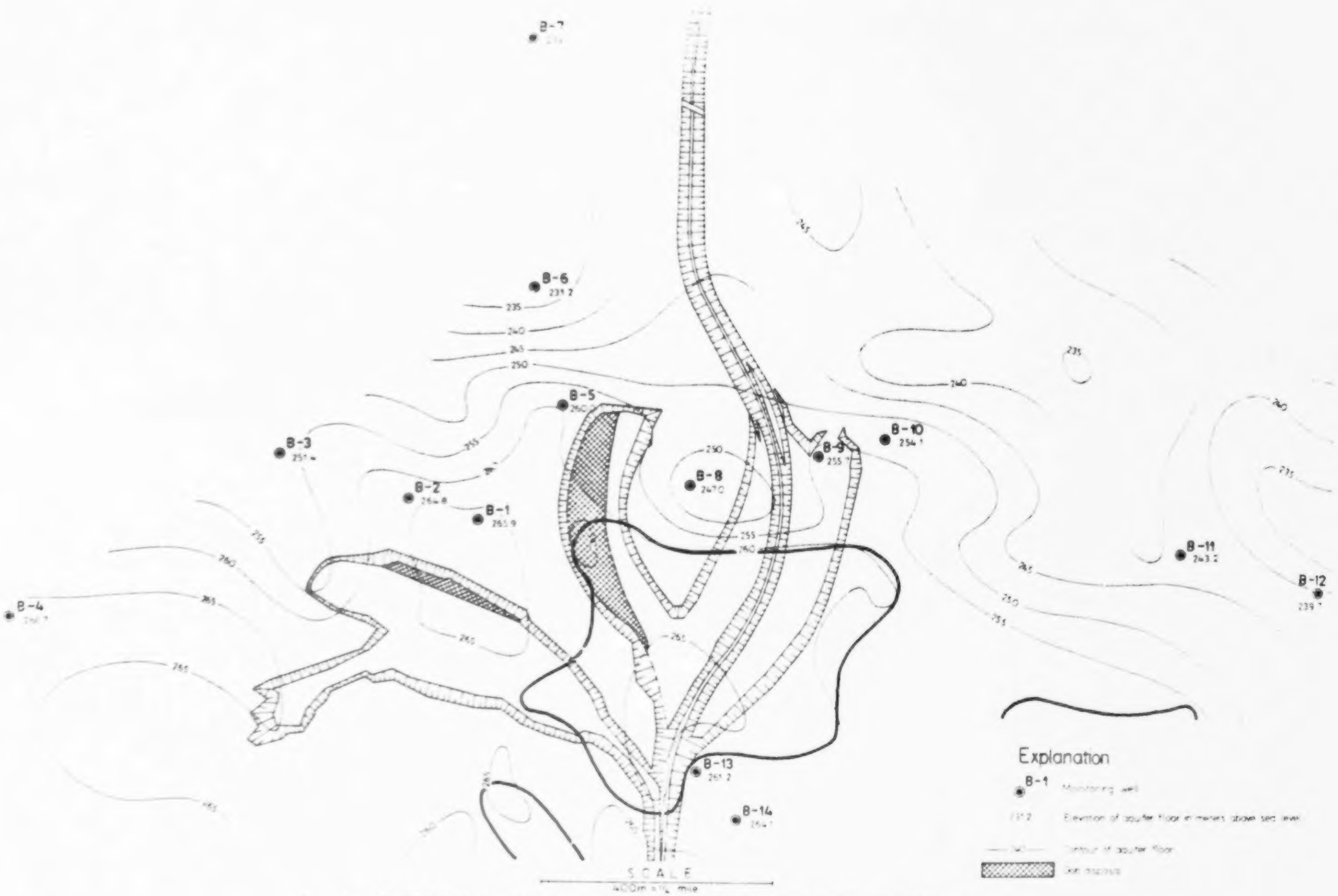

Fig. 44 DISPOSAL № 2 THE CONTOUR MAP OF AQUIFER FLOOR

for farer placed wells only for layers occurring below the ground water table. Values of the permeability coefficient for unsaturated layers in the neighbourhood of the disposal amount to from 4 to 26 m/24 hrs and respective values of specific yield fluctuate within limits of 0.12 to 0.18. Respective values for the saturated layers on the whole tested area fluctuate extremally within limits of 1 to 33 m/24 hrs, whereto majority of layers indicate values from 3 to 10 m/24 hrs. The corresponding values of specific yield fluctuate within limits of 0.11 to 0.15.

The thickness of waterlogged layer with the above parameters of permeability fluctuates within limits of 1 to 12 m. The table of ground waters occurs at depth of 6.5 to 15 m from the terrain surface and only at the bottom of the main open pit where the sand was excavated this is at depth of from 0.2 to 2 m. Considering the absolute values of the position of the water table one can say that within the range of the disposal these values will fluctuate within limits of + 263 to + 266 m a. s. l. In the Northern direction water table elevation falls at first gently to about 262 m a.s.l. and then quite rapidly to + 249 m.a.s.l. In the Eastern direction the occurrence of the water table inclination has a gentler character and more regular - it declines by about 6 m within the first 400 m and by further 10 m, on the following 700 m distance. In the Southern and South-Western direction the decrease in the water table is very small - within 2 m mark per 400 m. In the Western and North - Western direction this inclination is more irregular whereby the lowest elevation of the water table is coming to about + 253 m.a.s.l.

Observations of the water table position performed at time intervals of about 3 weeks indicated that changes in particular wells did not exceed 70 cm. A clear increase of the water table in the year 1975 (10 to 70 cm) was observed in relation to the 1974 year, resulting from increased amount of precipitations in relation to long term averages.

Velocities of the flow in the ground water stream in the region of the disposal (computed on the basis of heads distribution and permeability parameters) fluctuate within 0.15 to 3 m/day limits.

Finally one more parameter should be mentioned, namely the coefficient of infiltration. In conditions of empty abandoned open pit without surface run - off and without continuous vegetation cover, this can fluctuate within limits of 0.6 to 0.8 on a 24 hrs scale, and within limits 0.4 to 0.6 in a yearly scale. In conditions of open pit filled with waste material flush with the surrounding terrain and with no vegetation introduction this is values respectively to be from 0.4 to 0.7 and 0.3 to 0.5.

ANALYSIS OF DISPOSAL FORMATION AND THE DISPOSAL MATERIAL

In the described hydrogeological conditions in Fifties significant amounts of sand were exploited for the stowing in deep coal mines. In the effect old abandoned open pits remained.

They consist of three separate, independent of one another excavations joined together only on their southern fringes. The central pit intended for main filling it with gob in first place has a length of about 450 m and a width 120 m. Elevation of the pit bottom is within limits of + 263,5 m above s.l. + 268 m above s.l., and its depth comes to 13-20 m. The remaining pits have similar dimensions and are intended for storage of gob in successive years. The Western pit has been foreseen to store in it (from the Northern side) gob in the time where on the main pit the necessity to move rails occured. This pit has similiar size and depth as the main one. The bottom and the slopes of the both pits are made of sands occacionally containing admixtures of gravels, silts and clays. The thickness of bottom sands in the northern part of the main open pit amounts to 7,5 m, in the southern direction this initially increases to about 8 m, then diminishes in places to zero, and in southern part increases again to about 5 m thickness. The water table occurs from 0 to 2 m below the floor of the disposal.

In the described above conditions, systematic storage of gob from a neighbourly deep coal mine commenced as from the 1-st of January 1975. The amounts of being stored were as follows.

January 1975	-	2.860 m^3
February	-	1.524 m^3
March	-	10.985 m^3
April	-	12.516 m^3
May	-	26.730 m^3
June	-	31.800 m^3
July	-	43.990 m^3
August	-	40.710 m^3
September	-	34.260 m^3
October	-	46.625 m^3
November	-	44.200 m^3
December	-	44.200 m^3
January 1976	-	31.600 m^3
February	-	82.100 m^3
March	-	18.700 m^3
April	-	18.200 m^3
May	-	31.300 m^3
June	-	22.100 m^3
Total:		520.000 m^3 gob.

(In this amount about 70 % from washers and about 30 % from quarry operations).

About 470.000 m^3 was stored on the main disposal, and about 50.000 m^3 on the western disposal (parallel to the line of wells B-1, B-2). It came as a necessity to use this pit, as reserve during the time of the rail - track relocation.

On the diagram (fig. no. 46) are presented quantities of the stored material in 3-weeks time intervals between particular waters samplings, with the object to have a possibility of respective comparisons performance.

Fig. 45a. Disposal no. 2. Empty open-pit before storage

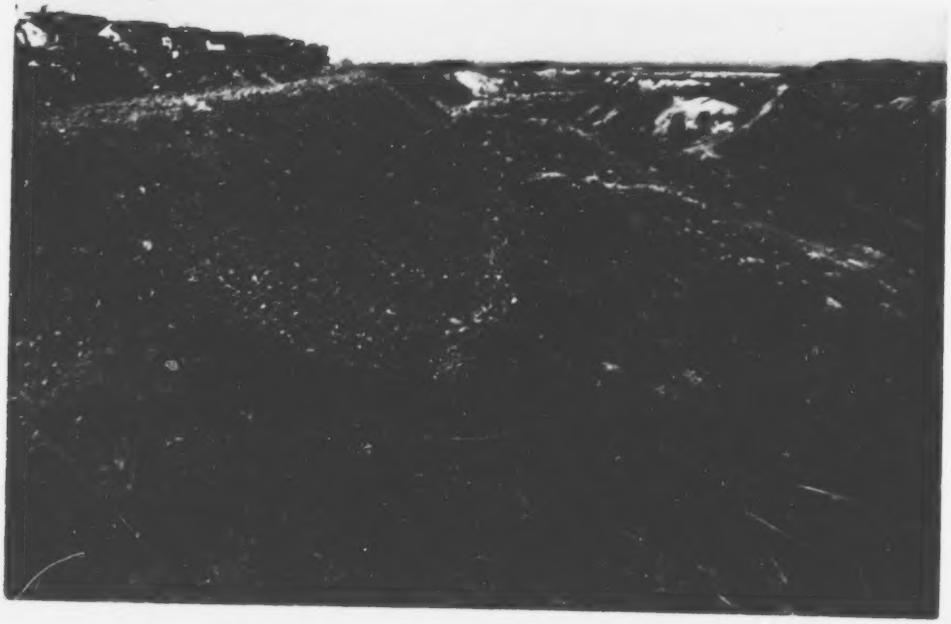

Fig. 45b. Disposal no. 2. Open-pit fulfilled in 60%. Storage operations.

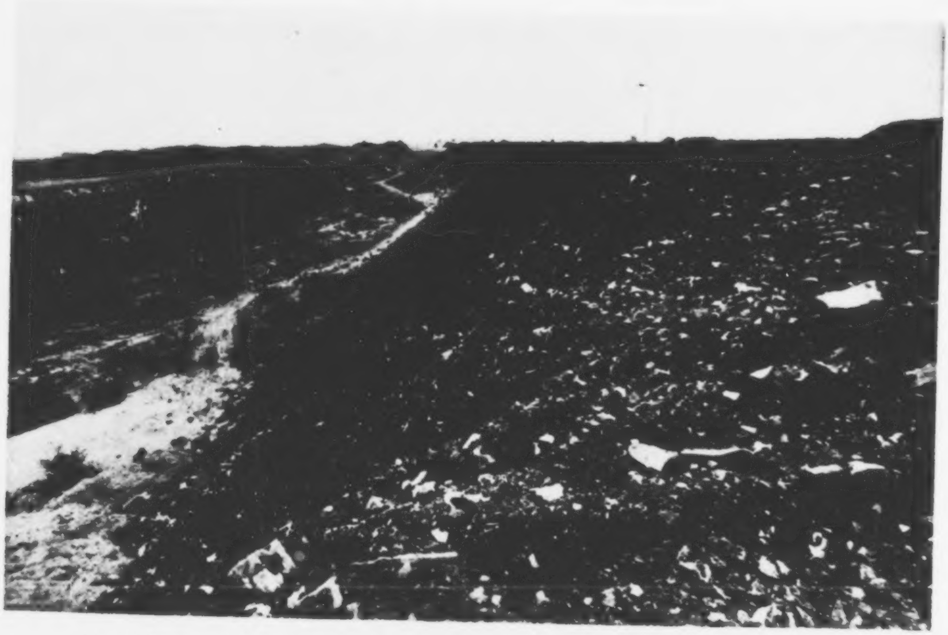

Fig. 45c. Disposal no. 2. Fulfilled in about 70%.

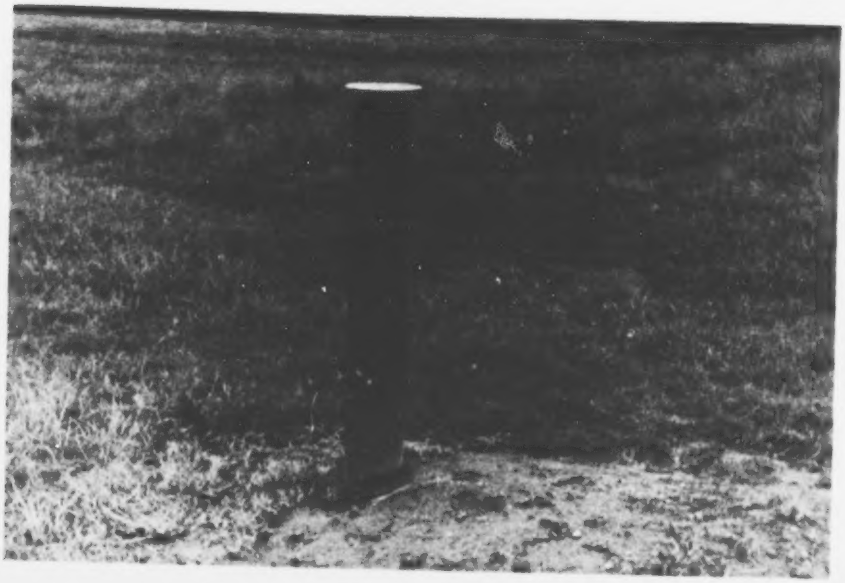

Fig. 45d. Disposal no. 2. Monitoring well.

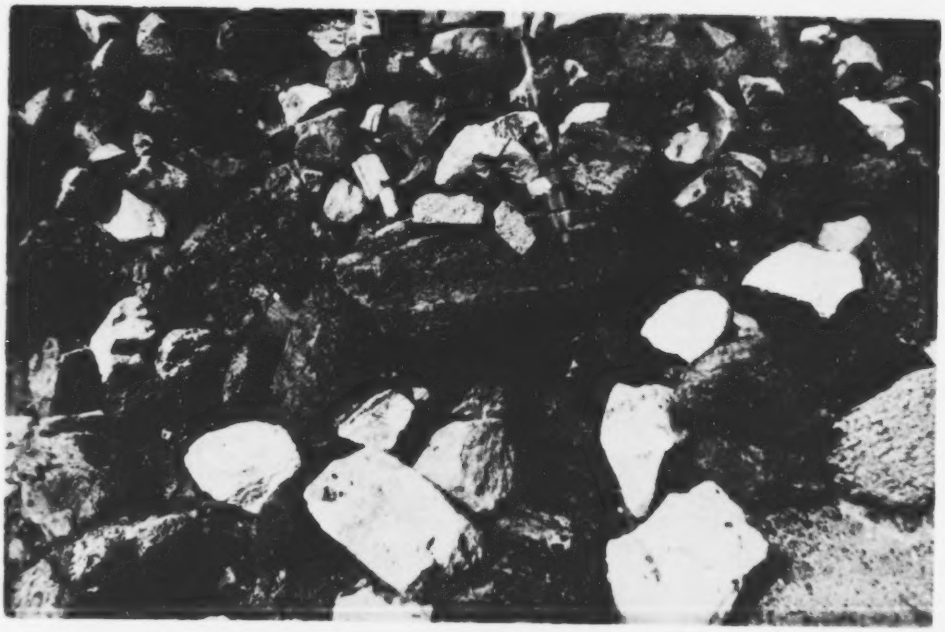

Fig. 45e. Disposal no. 2. Coarse gob.

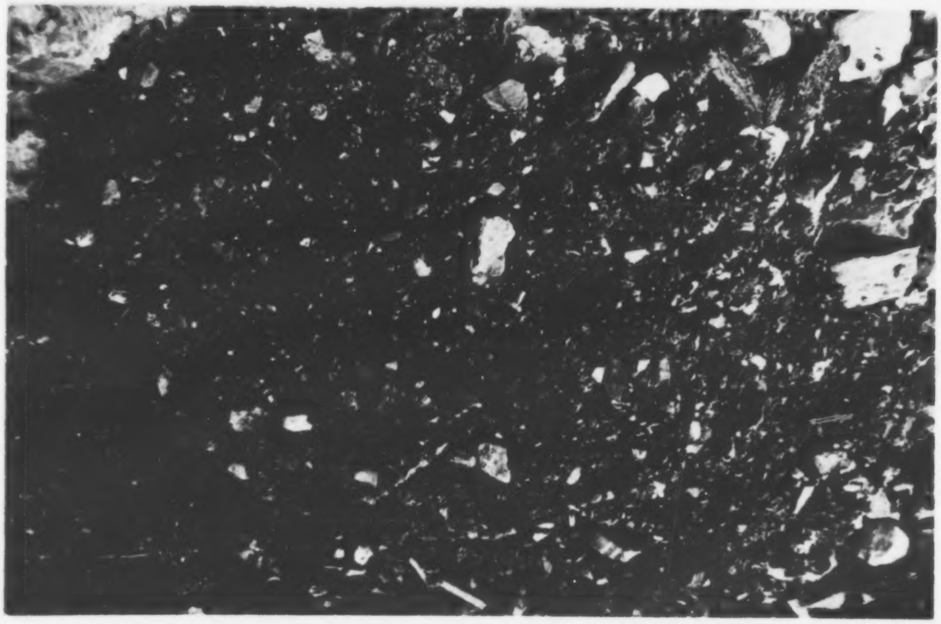

Fig. 45f. Disposal no. 2. Fine gob.

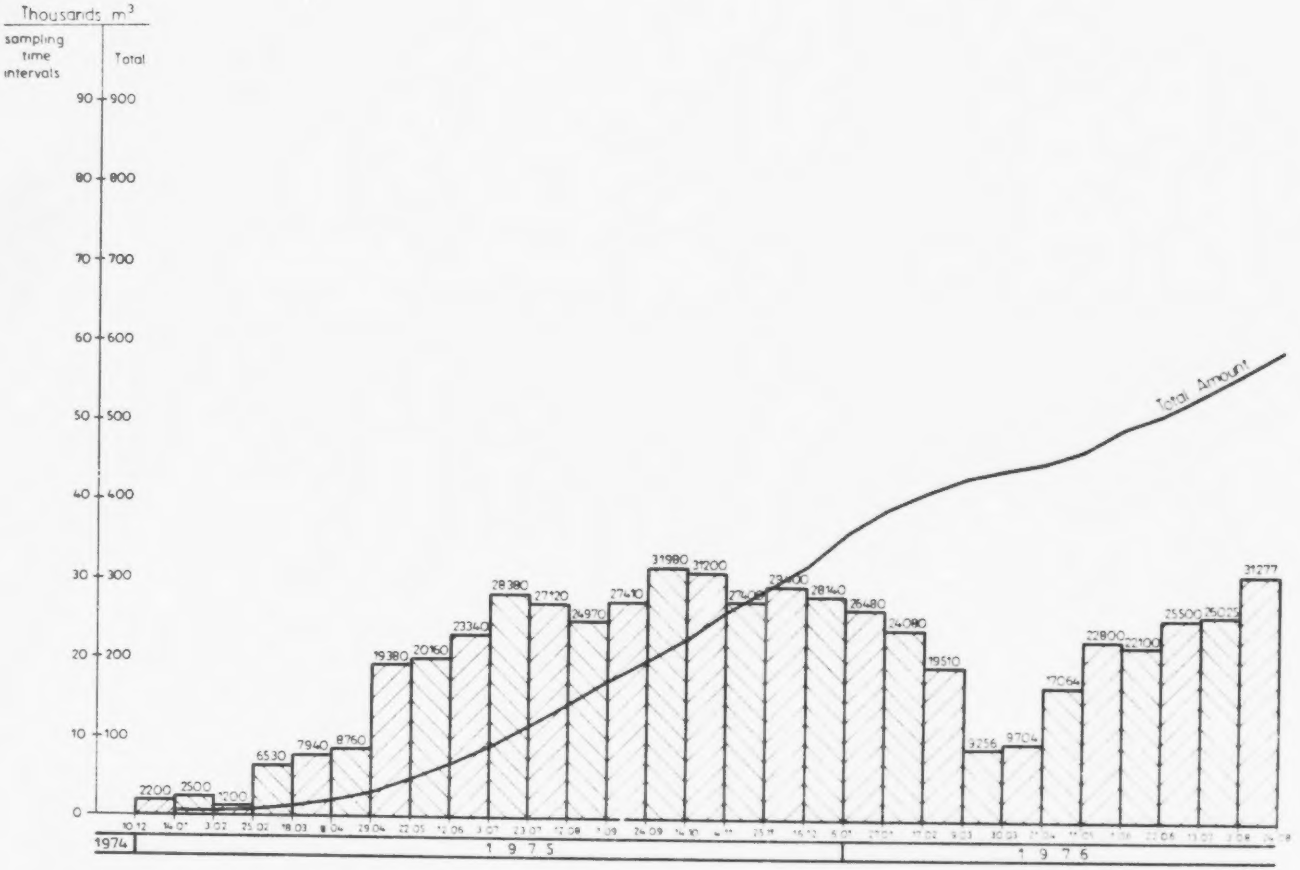

Fig.46 DISPOSAL № 2. THE DIAGRAM OF AMOUNTS OF GOB STORED IN SAMPLING TIME INTERVALS AND GROWING AMOUNTS OF TOTAL STORAGE

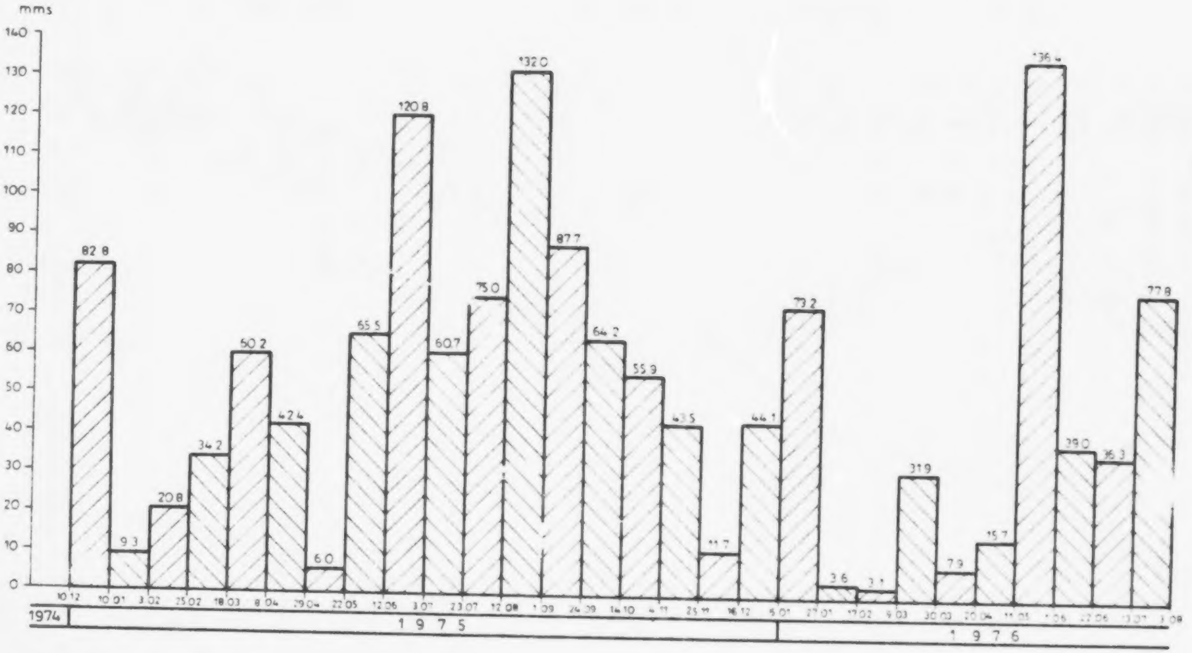

Fig. 47 DISPOSAL № 2. THE DIAGRAM OF PRECIPITATION AMOUNTS FOR SAMPLING TIME INTERVALS

For the determination of qualitative character of the stored material from the point of view of its susceptibility to leach particular ions, which could pollute ground waters, the following investigations were carried out. Samples of various wastes were taken from the disposal, and then placed in glass columns, 100 cm high and 12 cm in diameter, with a controlled underneath valve, offtaking the water.

The waste material in the bottom section of the column was underlined with a layer of sand collected from the floor of the disposal, whereby the ratio of the thickness waste material to the thickness of underlying sand was 4:1.

With the application of a peristaltic pump, leaching of material was carried out with distilled water flowing in closed circuit. Three consecutive leachings were performed with batches of water 5 dm^3, and each leaching was carried for 24 hrs. Filtration was made with the rates of 1 dm^3, and then 0,5 dm^3/hour. Due to the fact that these leachates contained considerable quantities of coal mud in the filtrate large amounts of colloidal sediments appeared which led at first gradually and then to a total sealing off the sand layer. This occurrence was hindering the performance of tests, but may have an important significance in the process of practical storage of this type of waste material. The washings from wastes silts and colcidal particles may seal off the bottom of disposal and prevent penetration of pollutants to ground waters.

Results of physico-chemical analyses of filtrate are illustrated on the table no. 7 - 3 to 7 - 6.

From this table it appears, that filtrates have a neutral - alkaline character (pH = 7,5 to 9,5), the dry residue reaches 10.385 mg/l value, total dissolved substances are up to 3500 mg/l, chlorides to 500 mg/l, sulphates to 330 mg/l, ammonium ion to 0,69 mg/l, phosphate ion to 0,322 mg/l, free cyanides to 0,030 mg/l, phenols to 1 mg l, total iron to 2,225 mg/l, manganese to 0,290 mg/l, calcium to 150 mg/l, magnesium to 5 mg/l, aluminium to 66 mg/l, chromium to 0,04 mg/l,

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The results of gob laboratory leachates analyses

May 22, 1975

Table 7-3

No.	Determination	Unit	Sample no. 1			Sample no. 2	
			S_1	S_2	S_3	S_1	S_2
1.	Smell		z2s	z2s	z2s	z1s	z2s
2.	Conductivity	us	1300	540	720	900	410
3.	pH		7,6	7,6	7,9	7,7	7,3
4.	Hardness	grades	0,80	0,65	-	0,75	0,65
5.	Basicity	mval/l	1,9	1,9	-	1,95	2,25
6.	Acidity	mval/l	0,22	0,16	-	0,20	0,10
7.	C.O.D. ind.	mg/l O_2	0,5	0,5	-	1,1	-
8.	C.O.D. org.	mg/l O_2	20,6	5,4	-	4,8	-
9.	T.D. subst.	mg/l	705	960	1348	2005	1480
10.	T.D. solids	mg/l	623	797	1078	1807	1319
11.	V.D. solids	mg/l	82	163	270	198	161
12.	Cl^-	mg/l	286	105	78	55	7
13.	SO_4^{--}	mg/l	58	37	27	281	39
14.	N_{NO_3}	mg/l	2,1	0,09	-	2.5	0,25
15.	N_{NO_2}	mg/l	0,035	0,040	-	0,001	0,054
16.	N_{NH_4}	mg/l	0,69	0,14	-	0,62	-
17.	N alb.	mg/l	0,37	-	-	-	-
18.	PO_4^{---}	mg/l	0,038	0,322	-	1,0	0,358
19.	CN^-	mg/l	0,007	0,008	-	0,016	0,015
20.	Phenols	mg/l	0,400	0,560	-	0,280	0,005
21.	Fe total	mg/l	0,530	1,525	-	2,225	0,775
22.	Fe^{++}	mg/l	0,030	0,880	-	1,680	0,332
23.	Fe^{+++}	mg/l	0,500	0,645	-	0,54	0,44
24.	Mn	mg/l	0,100	0,100	-	0,165	0,290
25.	Ca	mg/l	10	10	12	11	14
26.	Mg	mg/l	0,330	0,780	1,40	1,55	1,45
27.	Na	mg/l	217	137	164	216	117
28.	K	mg/l	9	5	6	10	6
29.	Al	mg/l	0,005	1,40	1,75	4,05	2,50
30.	Cr	mg/l	0,010	0,006	-	0,012	0,009
31.	As	mg/l	0,010	0,008	-	0,020	0,010
32.	Pb	mg/l	0,016	0,500	-	0,042	0,026
33.	Cu	mg/l	0,031	0,038	-	0,043	0,033
34.	Zn	mg/l	0,175	29,25	-	3,750	0,145
35.	Hg	ug/l	2,0	0,4	-	0,6	0,5
36.	Sr	mg/l	0,020	0,040	-	0,035	0,050
37.	SiO_2	mg/l	2,1	-	-	0,6	0,5
38.	B	mg/l	0,410	0,023	-	0,019	0,012
39.	Mo	mg/l	0,014	0,011	-	0,004	0,003
40.	Cd	mg/l	0,002	0,023	-	0,005	0,001

The Results of gob laboratory leachates analyses

June 1975

Table 7–4

No.	Determination	Unit	Sample no. 1			Sample no. 2		
			S_1	S_2	S_3	S_1	S_2	S_3
1	Smell		z1s	z1s	z2s	z1s	z1s	z1s
2	Conductivity	us	1800	680	400	900	500	300
3	pH reaction		7,4	7,75	7,55	7,6	7,85	7,9
4	Hardness	grades	1,1	0,7	1,6	0,4	0,7	0,4
5	Basicity	mval/l	1,6	1,9	1,7	2,2	1,9	1,8
6	Acidity	mval/l	0,20	0,16	0,12	0,20	0,12	0,12
7	C.O.D. inst.	mg/l O_2	0,8	1,0	0,5	1,7	1,0	0,9
8	C.O.D. org.	mg/l O_2	6,7	7,3	5,5	9,1	7,3	6,5
9	T.D.S.	mg/l	943	901	501	721	601	759
10	Cl^-	mg/l	300	91	42	91	43	16
11	SO_4^{--}	mg/l	198	66	40	157	72	41
12	N_{NO_3}	mg/l	1,65	0,18	0,02	1,25	0,58	0,02
13	N_{NO_2}	mg/l	0,003	0,016	0,006	0,003	0,013	0,011
14	N_{NO_4}	mg/l	0,07	0,21	0,22	0,56	0,05	0,03
15	Phenols	mg/l	0,220	0,160	0,014	0,230	0,023	0,016
16	SiO_2	mg/l	3,8	6,6	14,0	43,0	14,6	9,9
17	Fe (total)	mg/l	2,05	1,25	3,35	14,00	0,90	3,80
18	Mn	mg/l	0,098	0,159	0,111	0,710	0,162	0,131
19	Ca	mg/l	6,0	5,0	3,5	10,1	3,5	3,5
20	Mg	mg/l	0,60	0,80	0,65	3,25	1,55	0,30
21	Na	mg/l	415,0	158,0	93,0	222,0	116,0	93,0
22	K	mg/l	8,5	6,0	4,0	12,0	4,5	5,0
23	Al	mg/l	2,9	11,5	7,6	11,3	6,7	5,8
24	As	mg/l	0,017	0,012	0,010	0,020	0,012	0,010
25	Pb	mg/l	0,032	0,062	0,017	0,017	0,025	0,050
26	Cu	mg/l	0,010	0,020	0,016	0,064	0,031	0,047
27	Zn	mg/l	0,086	0,100	0,088	0,470	0,320	1,100
28	Hg	ug/l	1,5	1,2	1,2	0,9	0,7	0,6
29	Sr	mg/l	0,013	0,009	0,013	0,009	0,022	0,009
30	Cd	mg/l	0,0032	0,0025	0,0022	0,0032	0,0032	0,0022
31	Mo	mg/l	0,009	0,013	0,020	0,024	0,011	0,010
32	B	mg/l	0,355	0,061	0,076	0,028	0,091	0,039

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The results of gob laboratory leachates analyses

Table 7 – 5

No.	Determination	Unit	Sample – 25 Nov. 1975			Sample – 20 June, 1976		
			S_1	S_2	S_3	S_1	S_2	S_3
1.	Smell		z1s	z3s	z2s	z1s	z2s	z1s
2.	Conductivity	uS	900	790	450	630	210	170
3.	pH		7,85	7,4	7,65	8,0	9,1	9,5
4.	Hardness	grades	4,8	10,0	5,6	1,8	0,3	0,1
5.	Basicity	mval/l	0,9	–	1,1	2,7	1,7	1,2
6.	Acidity	mval/l	0,13	16,5	0,11	0,2	0,1	0,1
7.	C.O.D. ind.	mval/l	8,0	6,0	4,0	1,6	0,6	0,3
8.	C.O.D.	mg/l O_2	24,9	29,9	16,9	5,8	1,8	1,5
9.	T.D. subst.	mg/l	558	408	317	2412	688	272
10.	T.D. solids	mg/l	453	350	262	2280	580	198
11.	V.D.S.	mg/l	105	58	55	132	108	74
12.	Cl^-	mg/l	228,0	180,0	71,0	40,0	8,0	6,0
13.	SO_4^{--}	mg/l	50,0	51,5	65,3	103,0	9,4	5,2
14.	N_{NO_3}	mg/l	3,30	1,90	1,30	4,20	0,57	0,37
15.	N_{NO_2}	mg/l	0,044	0,019	0,092	0,220	0,079	0,043
16.	N_{NH_4}	mg/l	0,61	0,67	1,12	1,0	0,21	0,15
17.	PO_4	mg/l	0,026	0,048	0,078	0,01	0,024	0,032
18.	Phenols	mg/l	0,040	0,010	0,010	0,015	0,010	0,007
19.	Fe total	mg/l	0,670	23,1	0,095	2,150	2,240	0,050
20.	Mn	mg/l	0,175	0,555	0,220	0,084	0,066	0,032
21.	Ca	mg/l	55,0	40,0	55,0	1,7	1,5	2,0
22.	Mg	mg/l	3,10	0,40	2,00	1,87	0,83	0,78
23.	Na	mg/l	155,0	132,0	60,0	27,8	14,2	15,5
24.	K	mg/l	22,0	12,0	14,0	7,6	1,2	1,0
25.	Al	mg/l	0,05	0,05	0,075	2,60	1,40	1,0
26.	Cr	mg/l	0,012	0,013	0,016	0,002	0,005	0,006
27.	As	mg/l	0,003	0,005	0,004	0,011	0,018	0,058
28.	Pb	mg/l	0,032	0,125	0,036	0,070	0,035	0,028
29.	Cu	mg/l	0,007	0,040	0,005	0,134	0,026	0,026
30.	Zn	mg/l	0,065	0,300	0,039	0,335	0,120	0,057
31.	Mo	mg/l	0,007	0,008	0,006	0,008	0,004	0,004
32.	Cd	mg/l	0,005	0,047	0,004	0,0025	0,0034	0,0025
33.	Hg	ug/l	2,5	1,2	0,8	2,4	2,2	2,0
34.	Sr	mg/l	0,130	0,025	0,090	0,050	0,040	0,050
35.	B	mg/l	0,128	0,250	0,078	0,050	0,030	0,015
36.	SiO_2	mg/l	2,8	10,0	4,0	1,4	2,0	1,2

arsenic to 0,09 mg/l, lead tc 0,5 mg/l, ccpper to 0,19 mg/l, zinc to 29,25 mg/l, mercury tc 6,8 mg/l, strontium to 0,23 mg/l, boron to 0,44 mg/l, molybdenum to 0,046 mg/l, cadmium tc 0,060 mg/l. Particular ions showed different leachability which found its expression in their maximum occuring in first, second or third leaching.

MONITORING SYSTEM

In March of 1974 14 monitoring wells were drilled around the disposal localized according to the following criteria:

- wells numbered 1 to 4 were localized in the Western direction, at distances respectively 100 m, 250 m, 500 m, 1000 m from the dispcsal
- wells numbered from 5 tc 7, were made in the Northern direction with distances from the disposal 50 m, 250 m, 700 m respectively
- wells numbered 8-12 were placed in the Eastern direction with spacings respectively 100 m, 300 m, 400 m, 900 m and 1200 m from the disposal
- wells numbered 13 and 14 were sunk in the South Eastern direction at distances 150 m and 250 m.

Localization of the wells was determined by compromise of the following factors:

1) hydrogeological factors, especially the expected inclination of ground water table and the thickness of waterlogged sands
2) augmenting (in conformity with the propositions) spacing among the wells
3) possibility of access without infringement to rights of the land owners.

In such conditions this localization departed somewhat from the one adopted initially, but not in a way, that could have effect on the results of tests.

After the EHDA model hydrodynamic net reconstruction this location appeared as not the best. There is a lack of monitoring wells toward North - East direction where to the polluted streams flow most intensively. Monitoring wells no. B-11, B-12, and B-4 occured as not needed. Earlier reconstruction of hydrodynamic net was not possible because it was done on the base of data obtained from monitoring wells.

The depths of particular wells are within 7 to 27 m, whereby the completion of each well was down to the roof of continuous impermeable layer.

The wells were drilled with dry method.
All layers were accurately described in lithological respect and the coefficients of permeability and specific yield were determined. Following this a piezometric pipe ϕ 6" was installed in each well consisting of:

- section of pipe with solid walls, installed below filter, and a sedimentation portion at the bottom

- filter proper in a shape of a perforated pipe wrapped, round with a copper gauze and with gravel packing on the waterlogged section

- pipe above filter with solid wall protruding 1 m above the terrain surface and complete on top with a protecting cover closed with special key; clearance between the walls of the well and the pipe was suitably sealed off, in order to prevent direct infiltration of surface waters to the wells along the pipe.

WATER SAMPLING AND FIELD MEASUREMENTS

In the region of the proposed disposal beginning from the 9-th of April 1974 observations and investigations commenced with the object to determine if possible most accurately the initial state for the future research. Fulfillment of this with a particular exactness was necessary as the scale of the disposal size puts a question mark on the possibility of utilization of initial comparable water during the time of the disposal existence in the future. To parameters characteristic of this water were referred parameters of waters subjected to eventual outside pollutions. Comparable water, which could be collected at greater distance from the disposal might already undergo an influence of other factors affecting its quality differing from water which would have contact with the disposal. This series of tests was completed on the 19-th September 1974.

After a period of break (from 19 Sept. to 10 Dec.) begun were systematic investigations.
These investigations comprised:

- measurements of the water table position in all wells with an accuracy of ± 2 cm
- collection of waters for physico-chemical analyses.

The work was performed with the preservation of the following rules:

- measurements and water sampling at 3 weeks intervals
- method of water sampling similar as in case of the disposal no. 1, with a provision that the quantity of water removed from each well prior to the water sampling, was lesser (equal in approximation to the volume of the well). Due to a greater depth and non availability of electrical current this had to be performed by manial bailing, and as found from tests on the disposal no. 1, this scooping actually had no effect on the essential results;
- water from each well was collected always to the same containers,

- from November 1975, the collection of water from the well no. 4 was ceased (it was 1 km distant from the disposal with a higher water table position than in the region of disposal), owing to the fact that this well underwent a pollution of water from different than the disposal sources,
- in place of this sample commenced was a water sampling of effluents from the disposal slopes.

The method of sampling, preservation and the transportation of samples was similar as with disposal no 1 which is described in the section 6.

METHODOLOGY OF LABORATORY TESTS

The methodology of laboratory physico-chemical tests of water samples was indentical as described in pt. section 6 for the disposal no.1. Different only was the method of the laboratory tests of gob leaching in a water environment, but this is described in the section 7.

RESULTS AND DISCUSSION OF HYDROCHEMICAL RESEARCH

The entire results acquired from tests is presented on tables, the set of which is available in Poltegor and EPA Offices and also on enclosed diagrams (fig.no.48 to fig.no.69) synthetically illustrating the course of the phenomenon. Specified on the tables are all results of analyses for all samples collected from all monitoring wells, and additional analysis of waters collected from slope effluents.

On the enclosed diagrams for the sake of synthesis and visualization of results, shown is on a semilogarithmic scale the scope of changes in the content of particular components of waters:

- in the shape of a narrow column along the vertical axis, the scope of variability of given component in the year 1974, i.e. before the commenced storing of gob

- in a shape of a lower strip the range of the waters´ each component variability from the moment of commenced gob storing, with emphasized maxima in wells subjected in the first succession to the influence of the disposal due to their localization and hydrogeological conditions

- in the shape of upper strip the content variability of the same components, obtained from laboratory leachates.

Due to the fact, that the described in this chapter wastes´disposal is very large, and the area comprised by the research has a diameter of over 2 km, the investigations now performed are in an initial phase. One anticipates their continuation for the period of subsequent 3 years.

For this reason the too detailed discussion of the results is premature, and would be not necessary in this report which in a sense composes a closed entity.

It was decided, to include only diagrams alone without commentaries for any of the analysed elements, which should suffice in this phase.

These diagrams illustrate potential threat to ground waters posed by particular polluting components. This last manifestation is also partially illustrated on maps showing the course of the waves of pollutant flows. The material presented in these circumstances was provided only with initial conclusions.

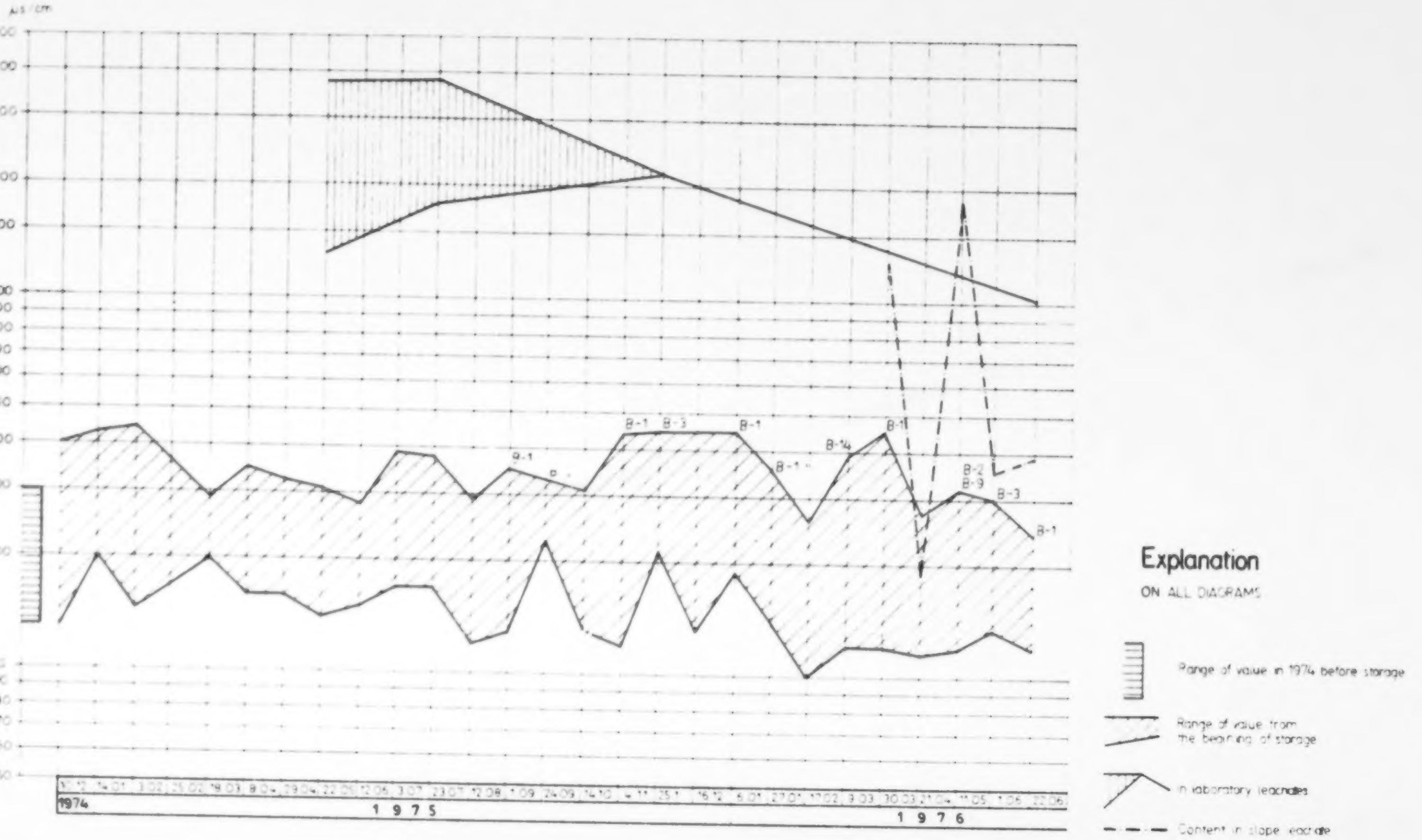


Fig. 48 DISPOSAL № 2. DIAGRAM OF CONDUCTIVITY

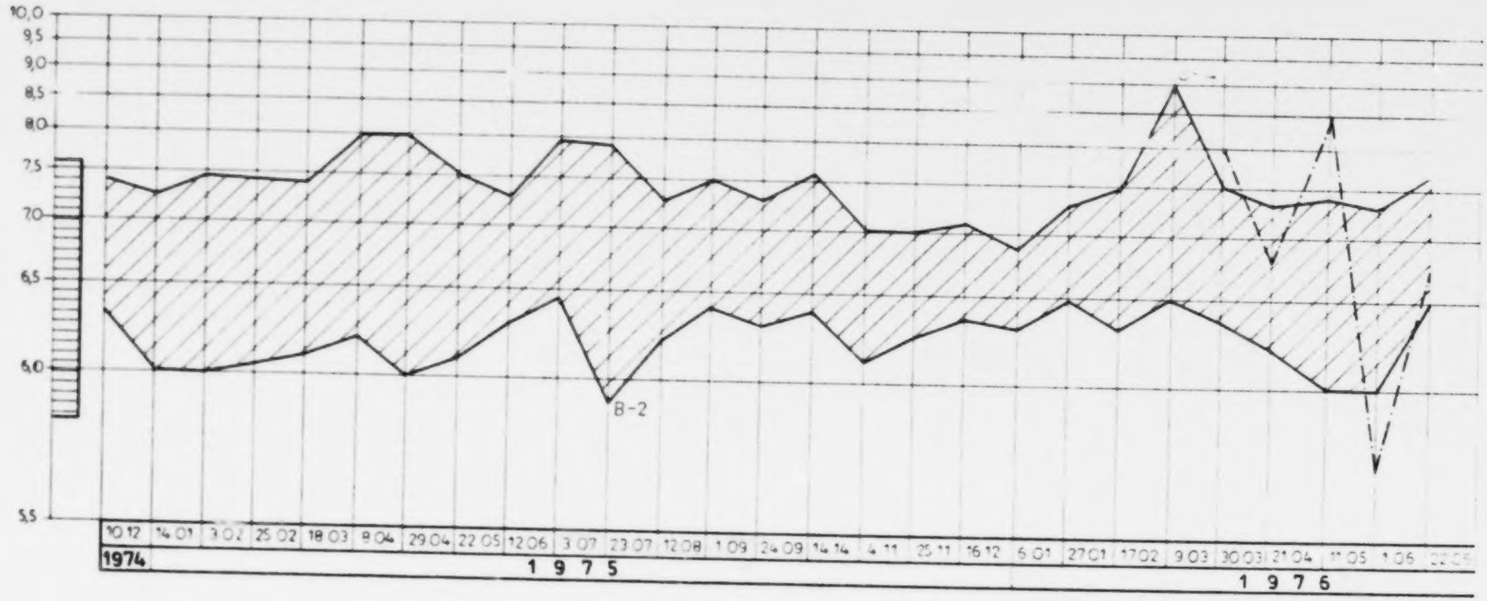


Fig.49 DISPOSAL Nº 2. DIAGRAM OF pH

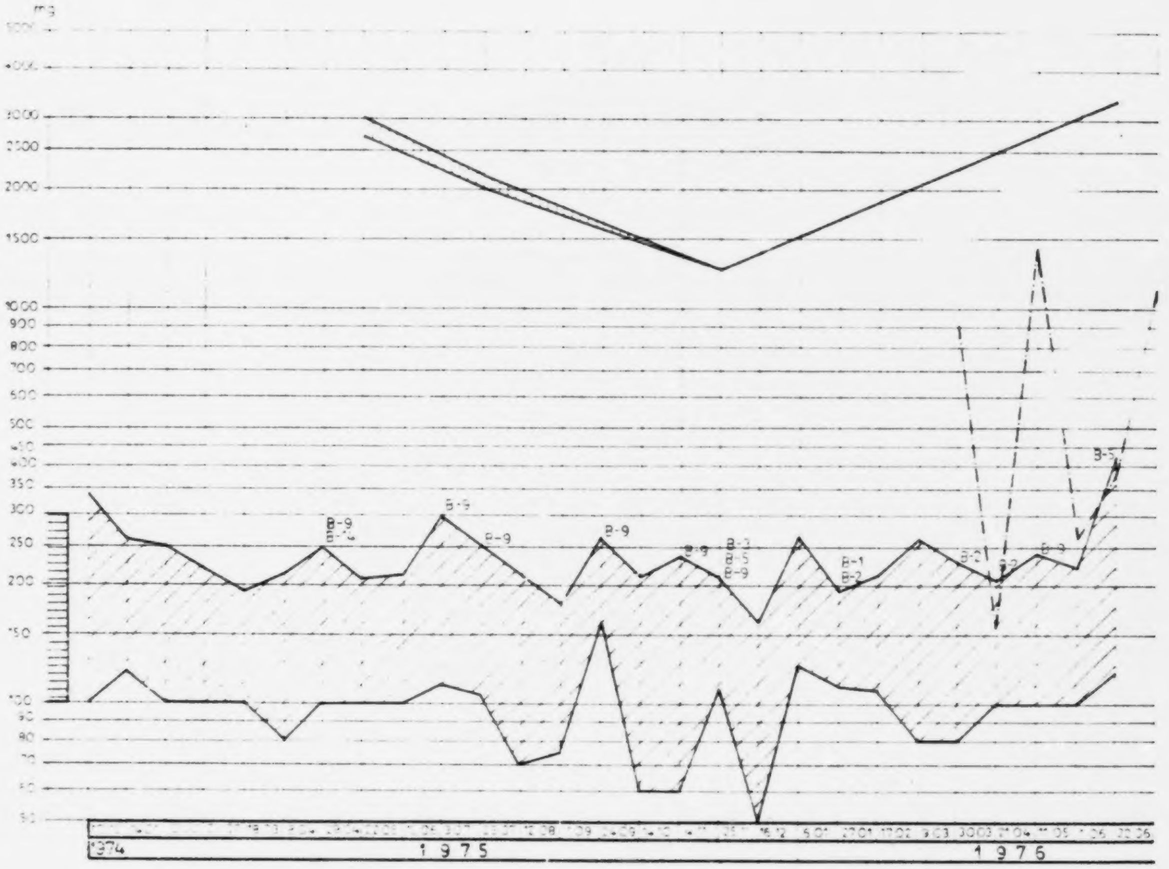


Fig. 50 DISPOSAL №2. DIAGRAM OF TDS CONTENT

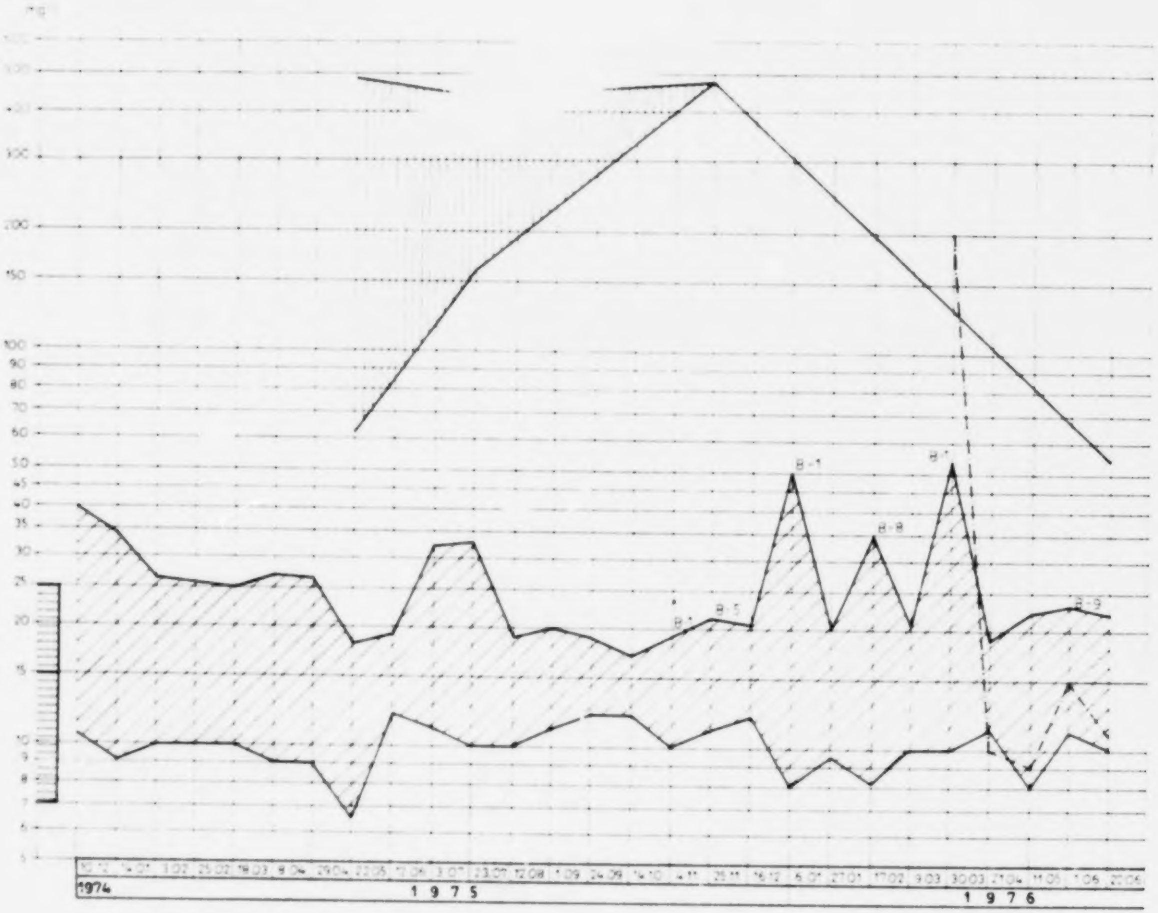


Fig.51 DISPOSAL Nº 2. DIAGRAM OF Cl⁻-ION CONTENT

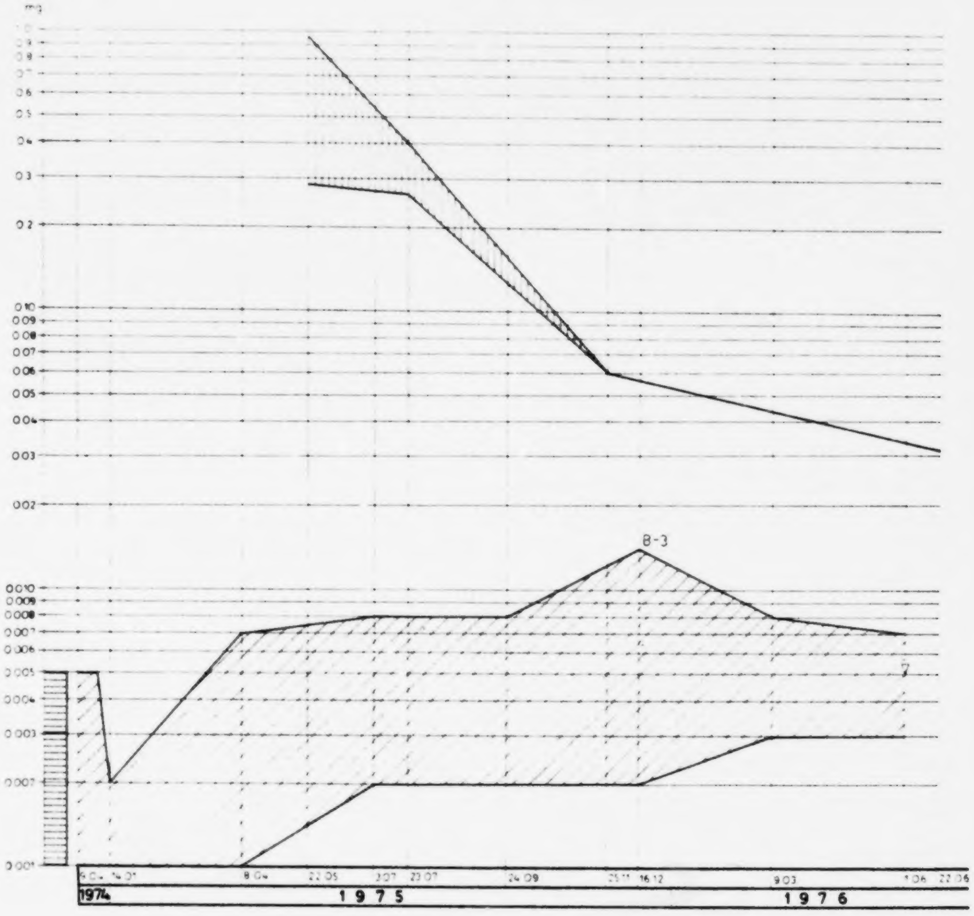


Fig. 57 DISPOSAL Nº 2. DIAGRAM OF PHENOLS CONTENT

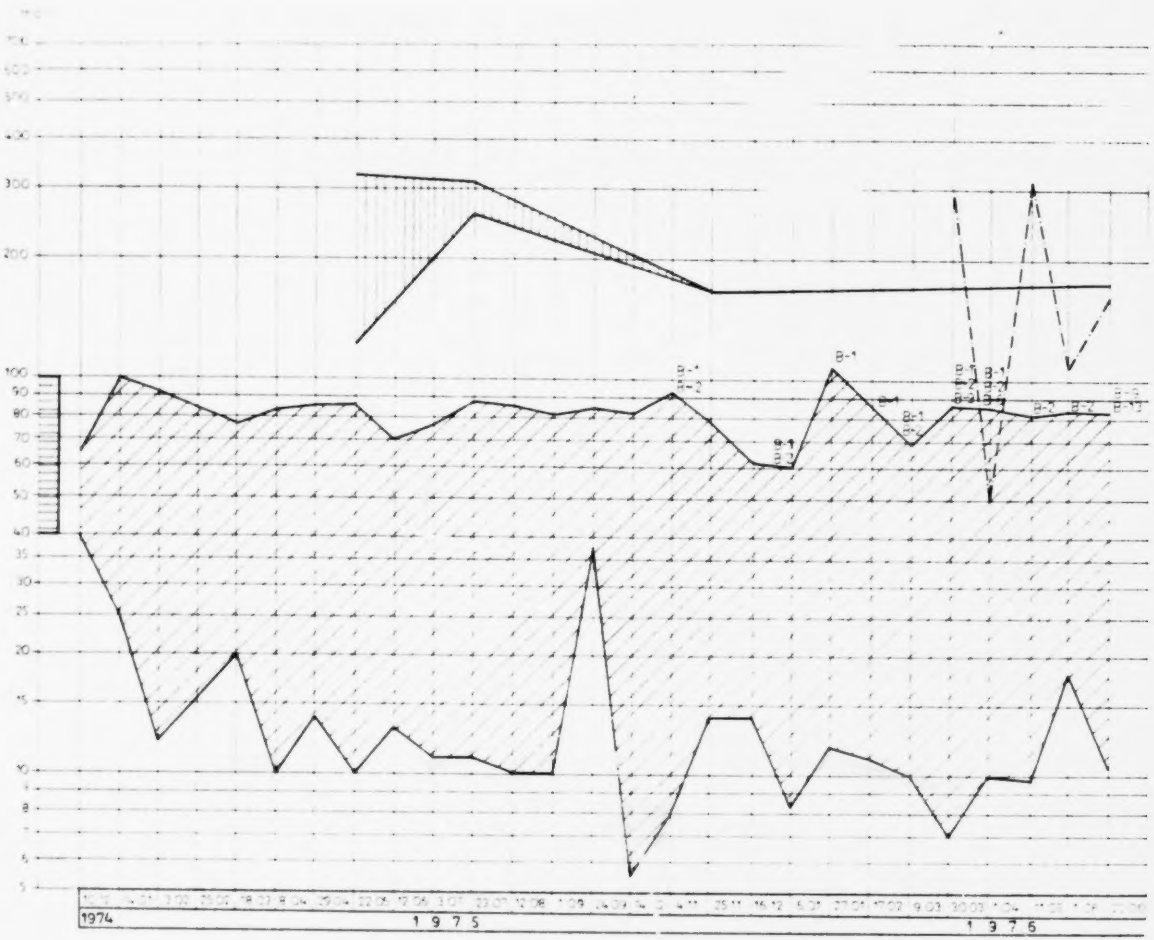


Fig. 52 DISPOSAL № 2 DIAGRAM OF SO_4^{-2} -ION CONTENT

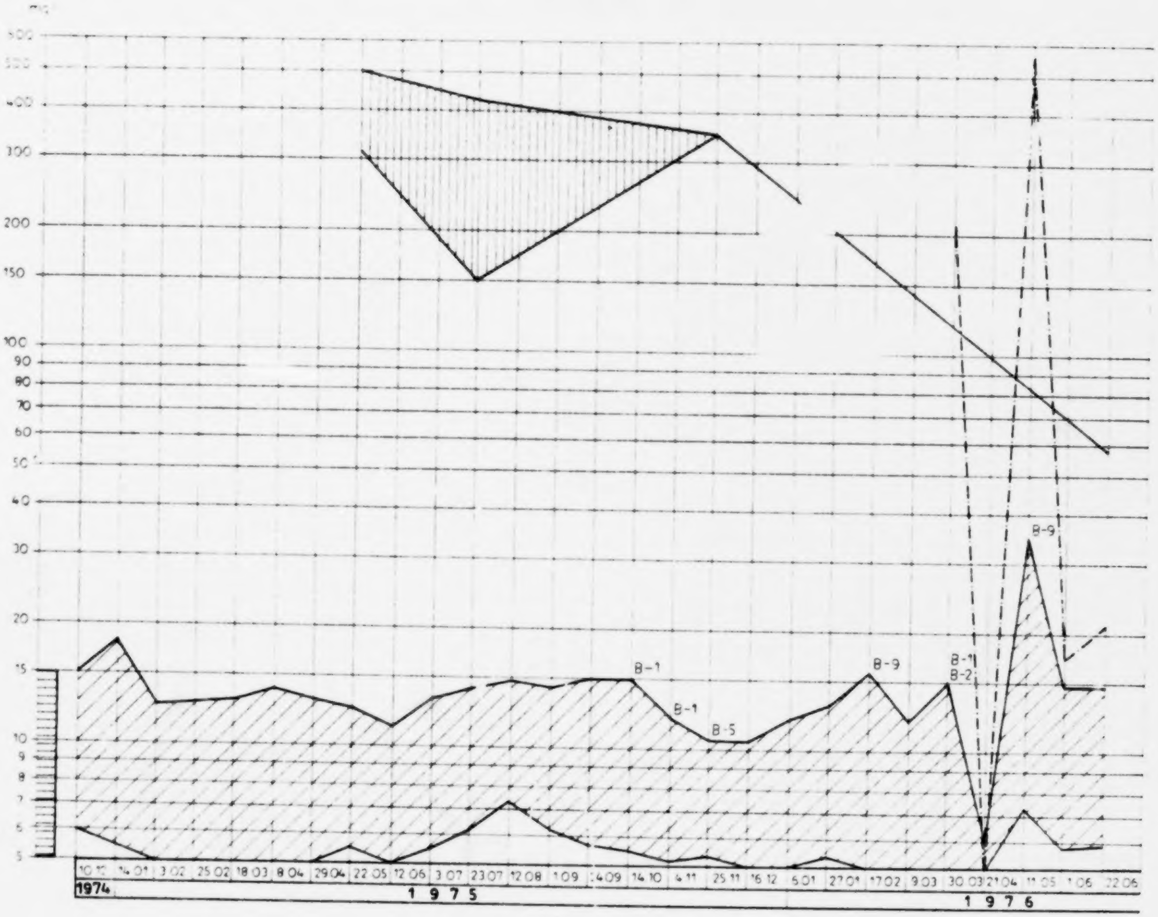


Fig. 53 DISPOSAL № 2. DIAGRAM OF Na⁺-ION CONTENT

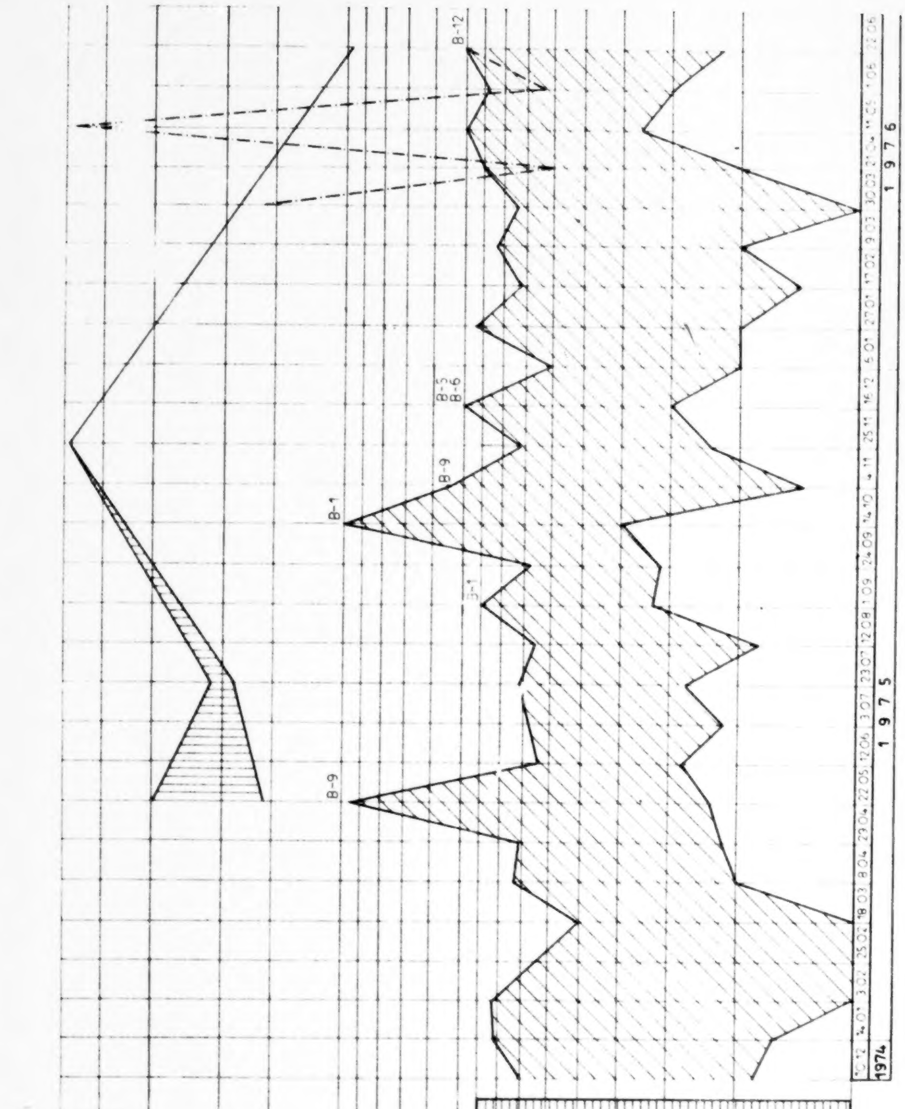


Fig. 54 DISPOSAL Nº 2. DIAGRAM OF K^+-ION CONTENT

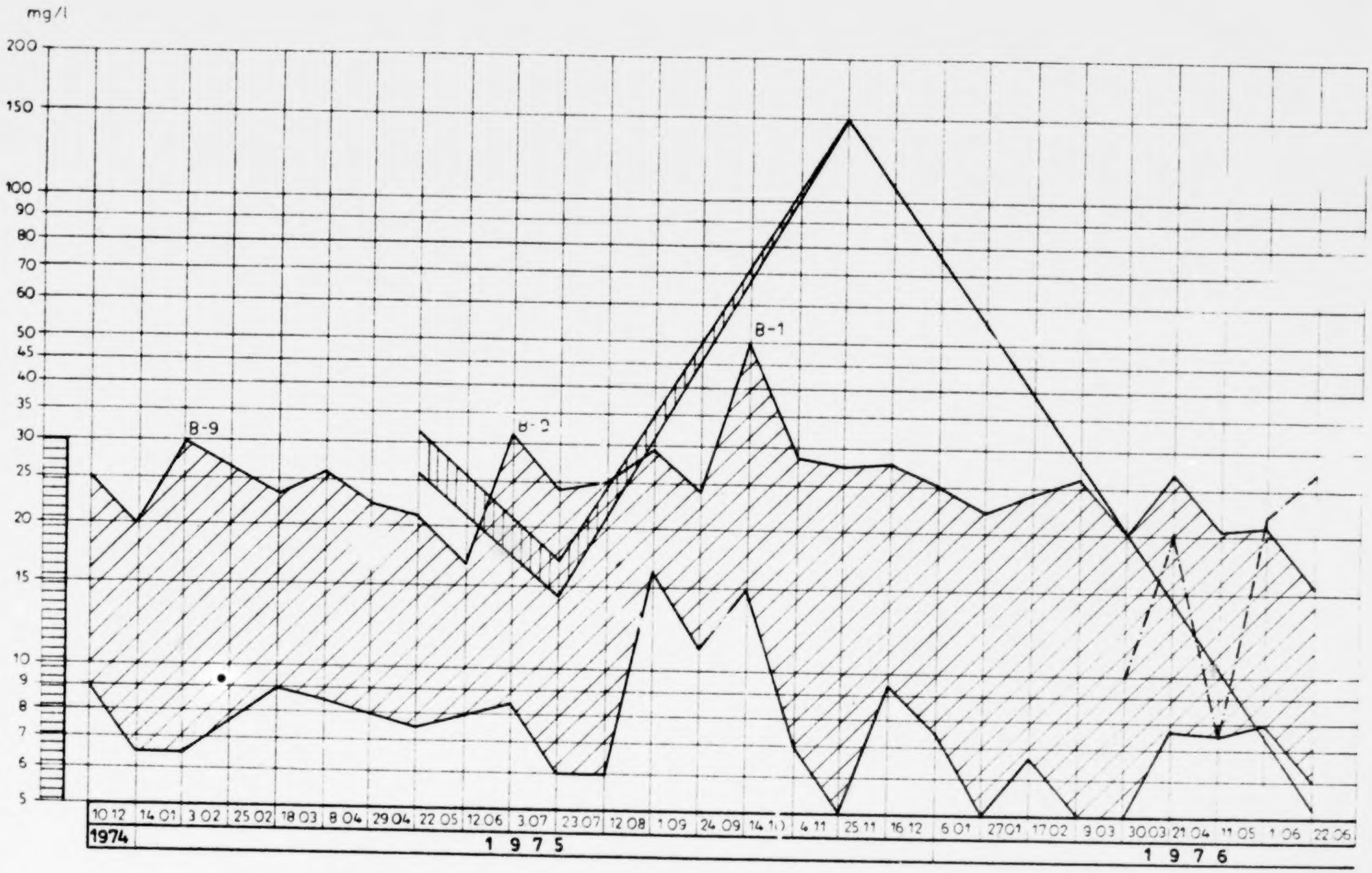


Fig. 55 DISPOSAL Nº 2. DIAGRAM OF Ca^{+2} -ION CONTENT

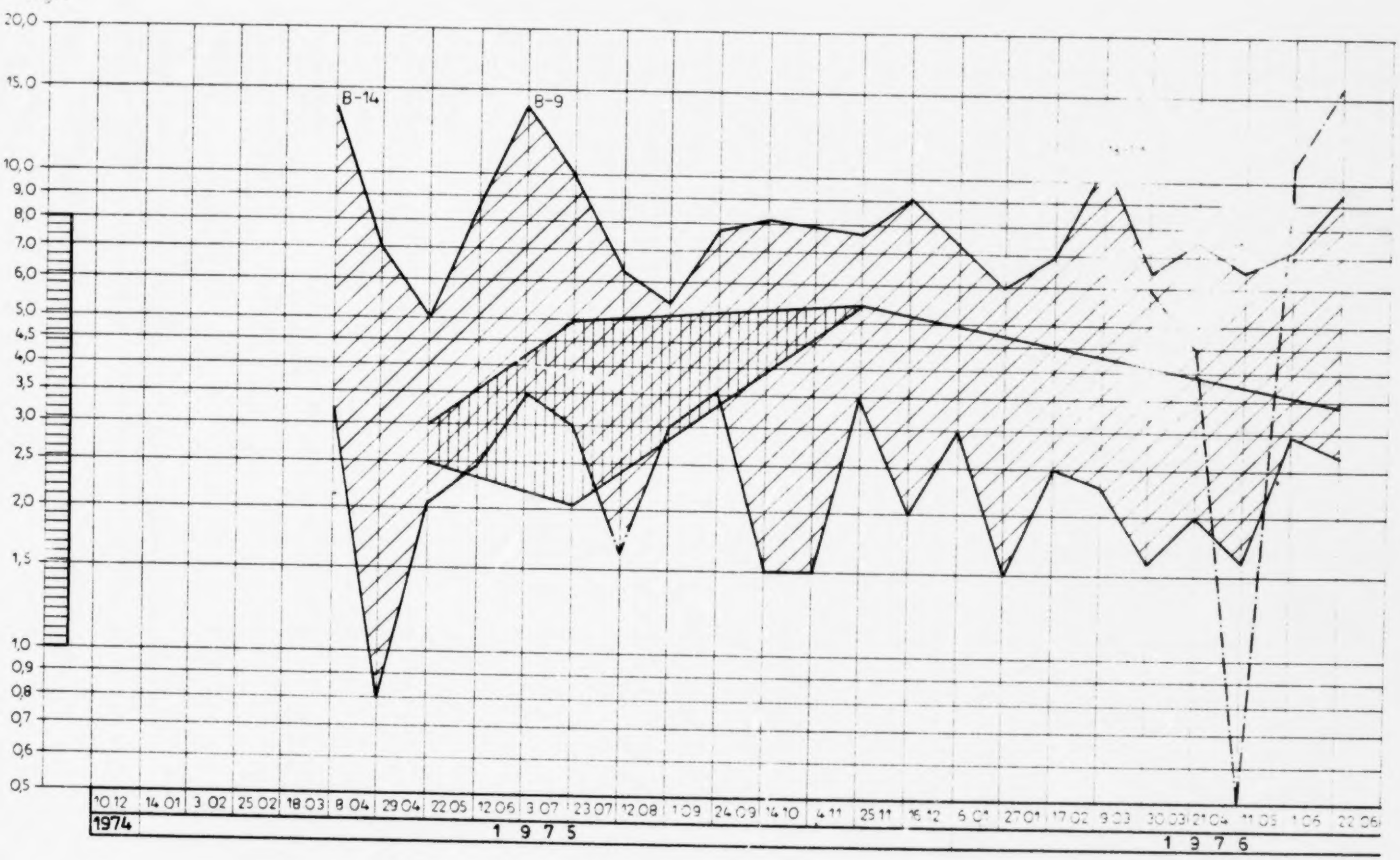


Fig. 56 DISPOSAL № 2. DIAGRAM OF Mg^{+2} -ION CONTENT

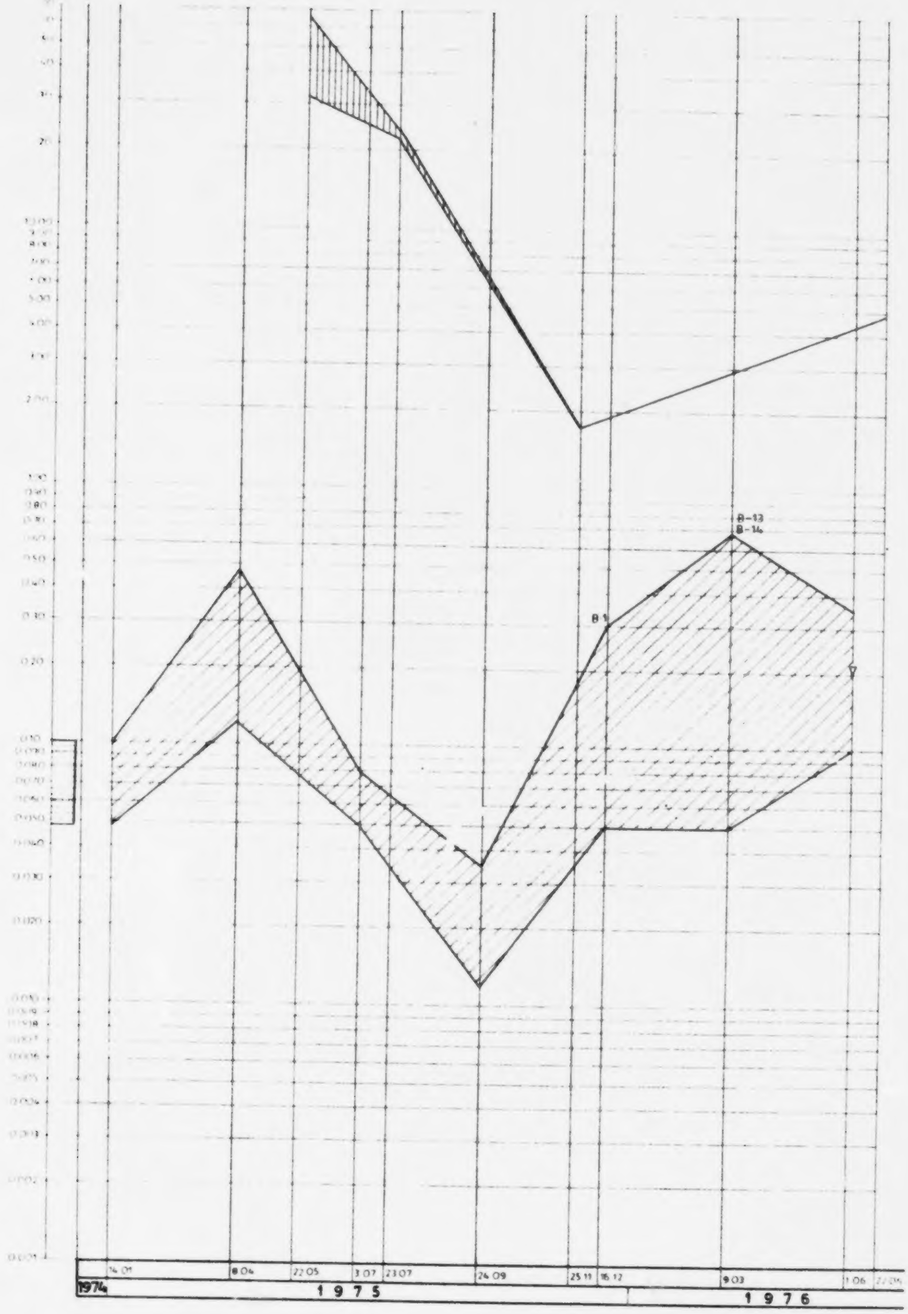


Fig. 58 DISPOSAL №2. DIAGRAM OF Al-ION CONTENT

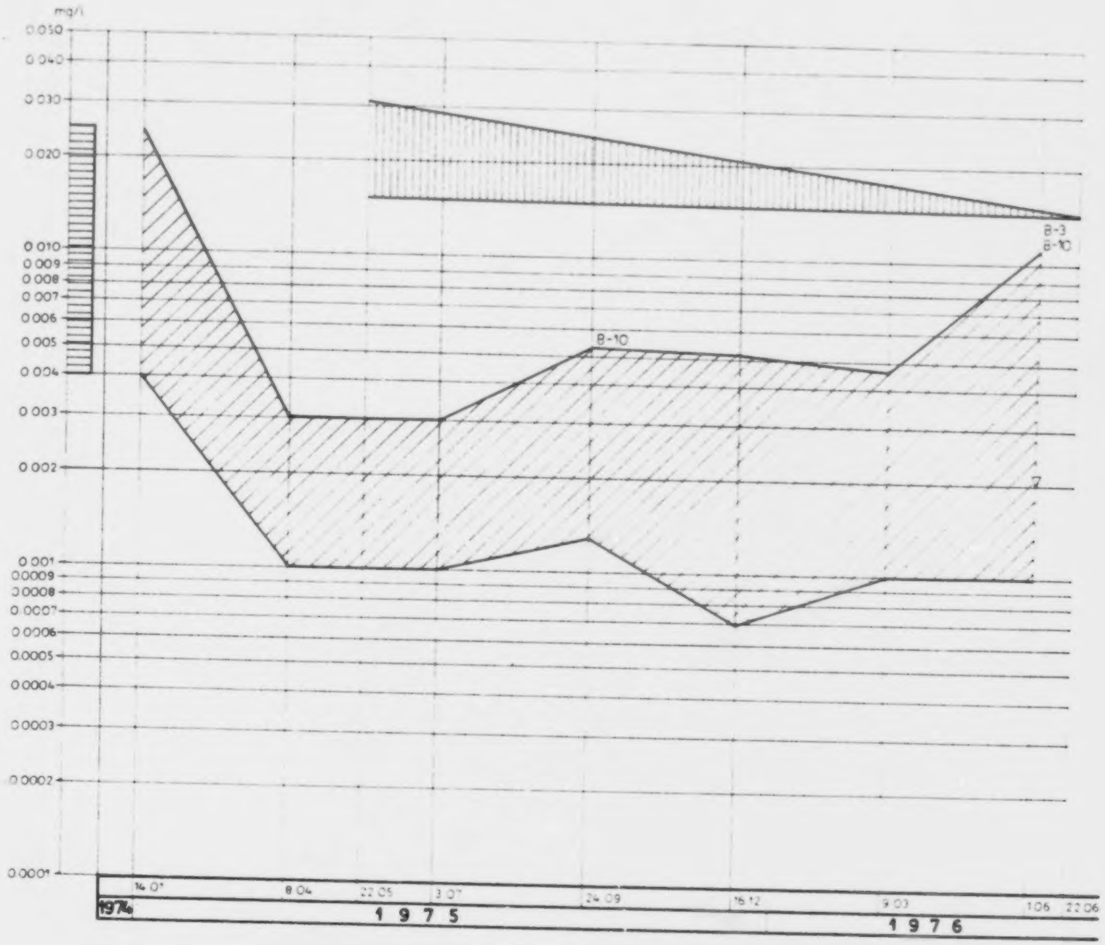


Fig. 59 DISPOSAL Nº 2. DIAGRAM OF CN - ION CONTENT

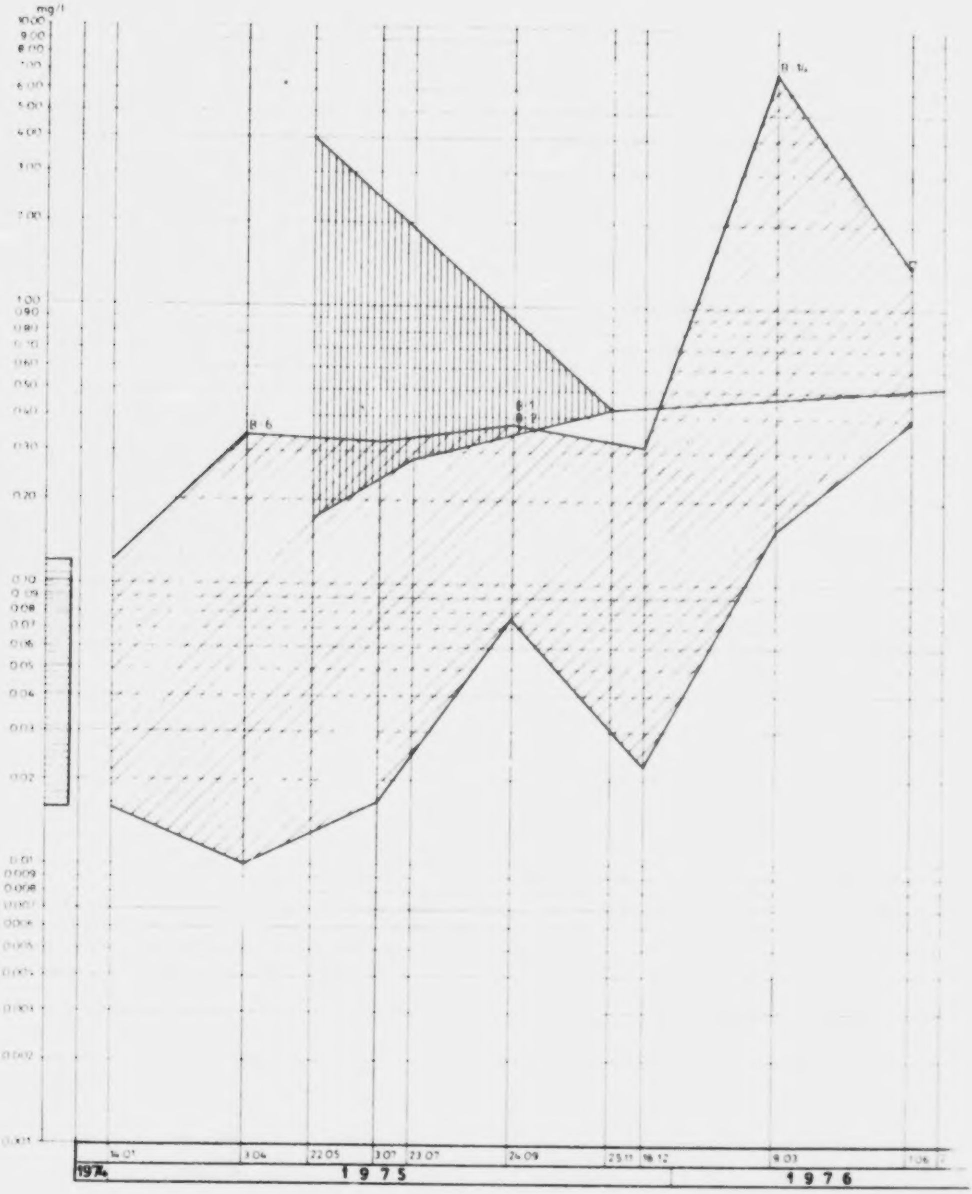


Fig. 60 DISPOSAL № 2. DIAGRAM OF Zn-ION CONTENT

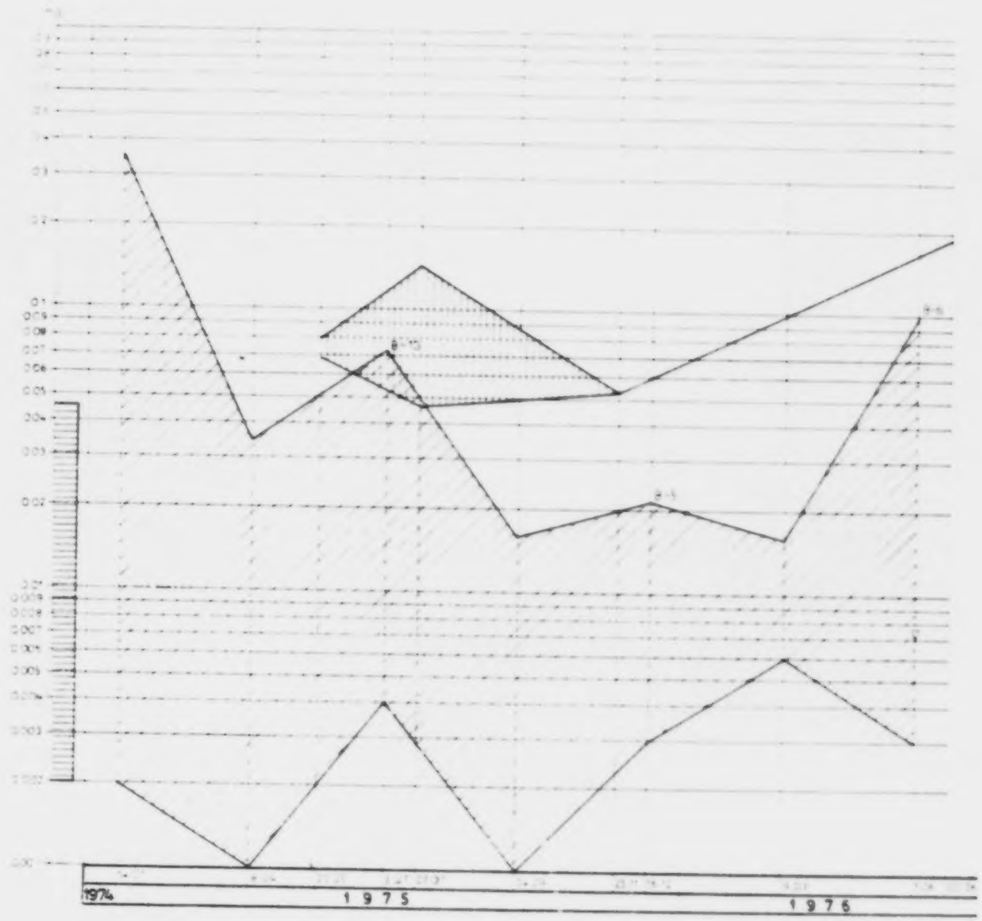


Fig.61 DISPOSAL Nº 2. DIAGRAM OF Cu-ION CONTENT

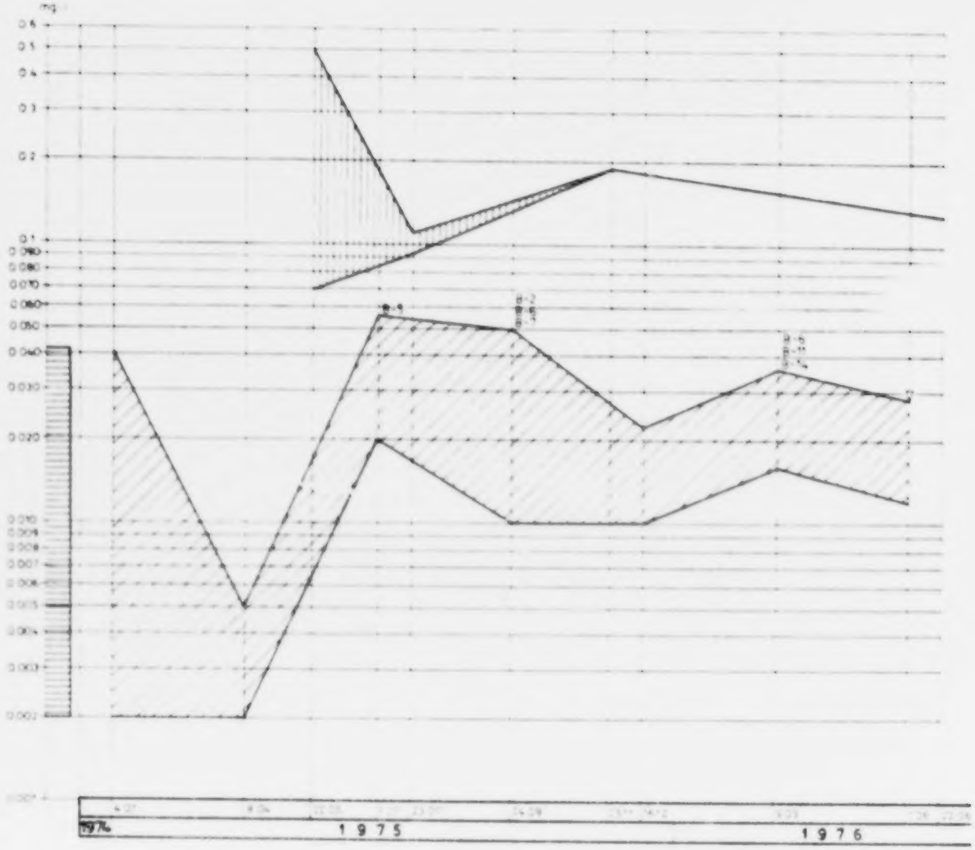


Fig 62 DISPOSAL Nº2 DIAGRAM OF Pb-ION CONTENT

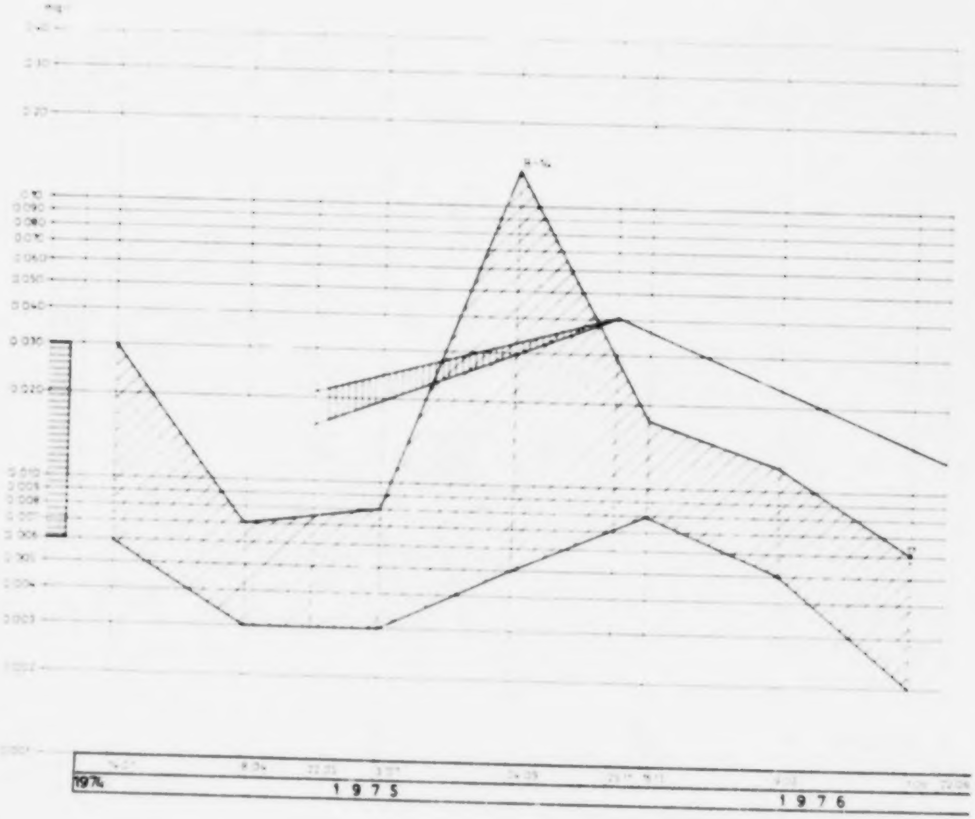


Fig. 63 DISPOSAL Nº 2 DIAGRAM OF Cr-ION CONTENT

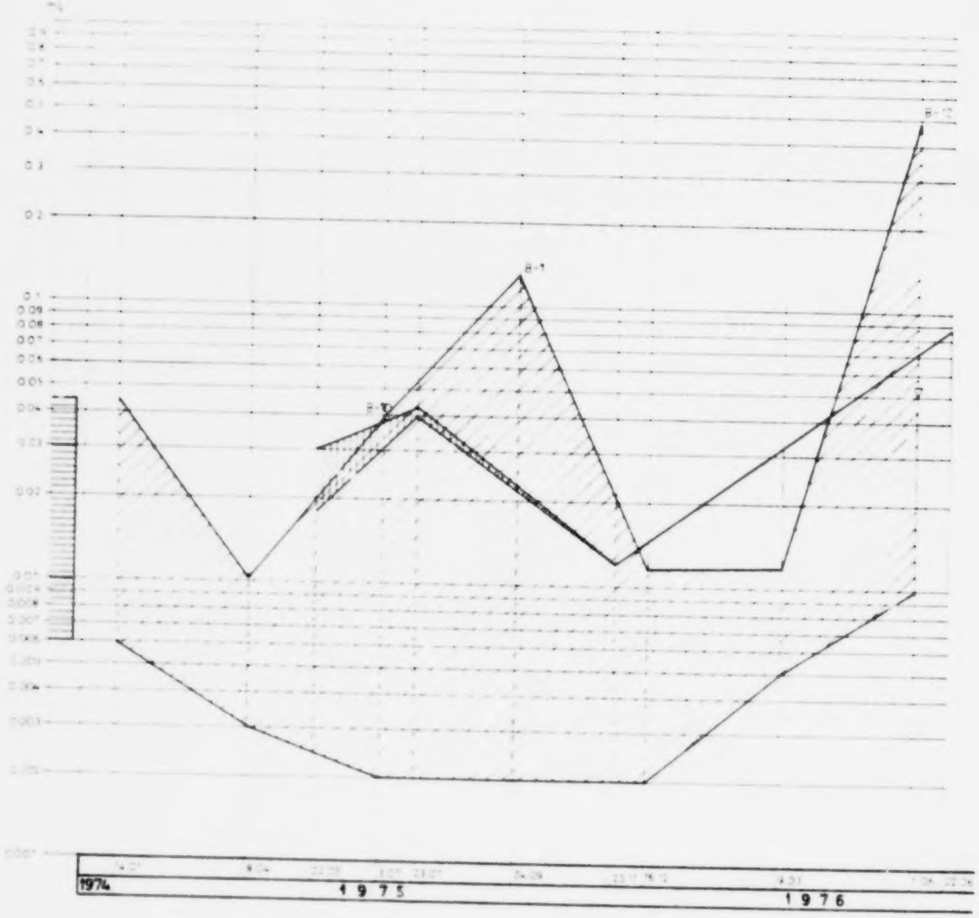


Fig 64 DISPOSAL № 2 DIAGRAM OF As-ION CONTENT

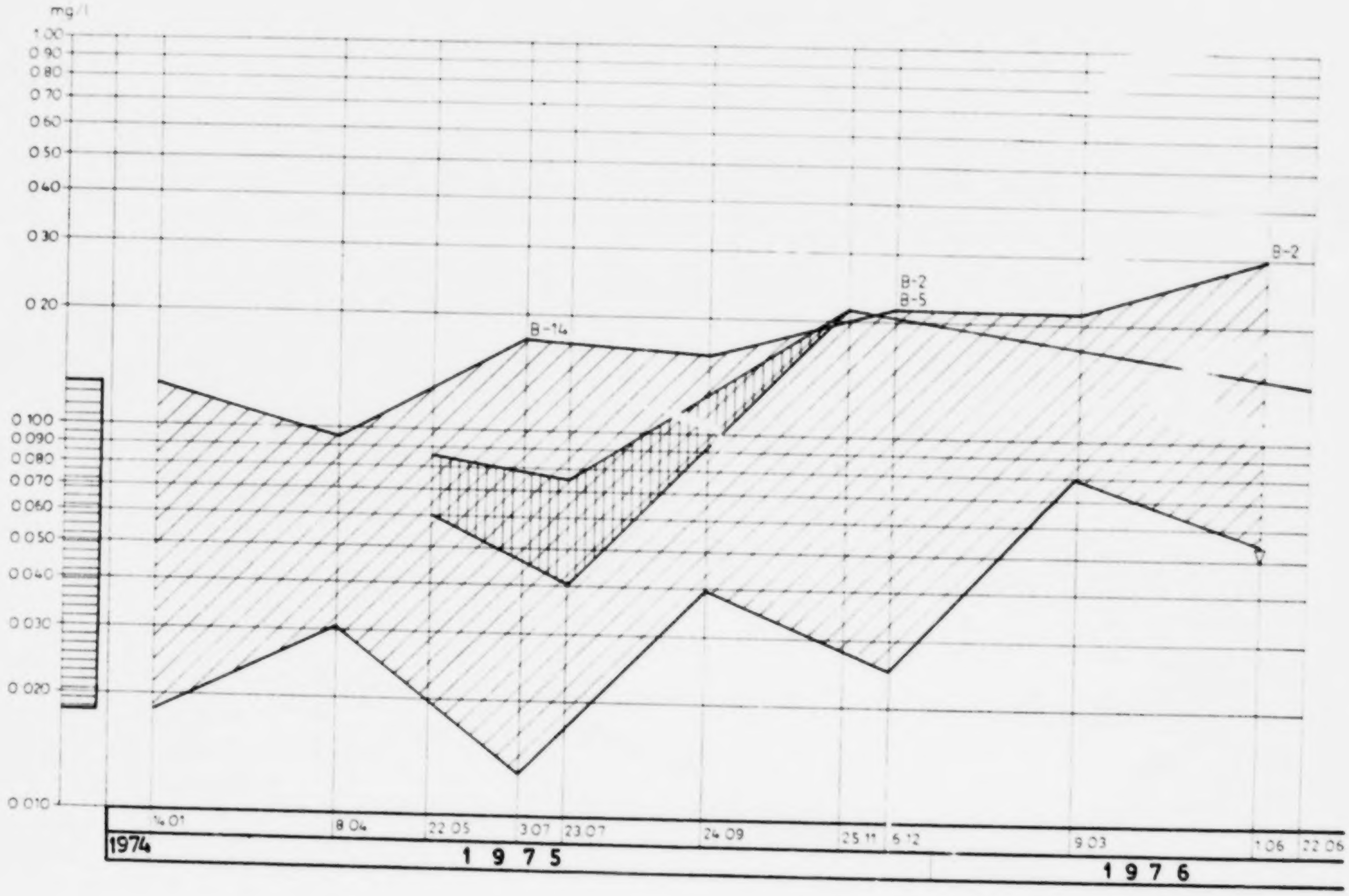


Fig. 65 DISPOSAL № 2. DIAGRAM OF Sr - ION CONTENT

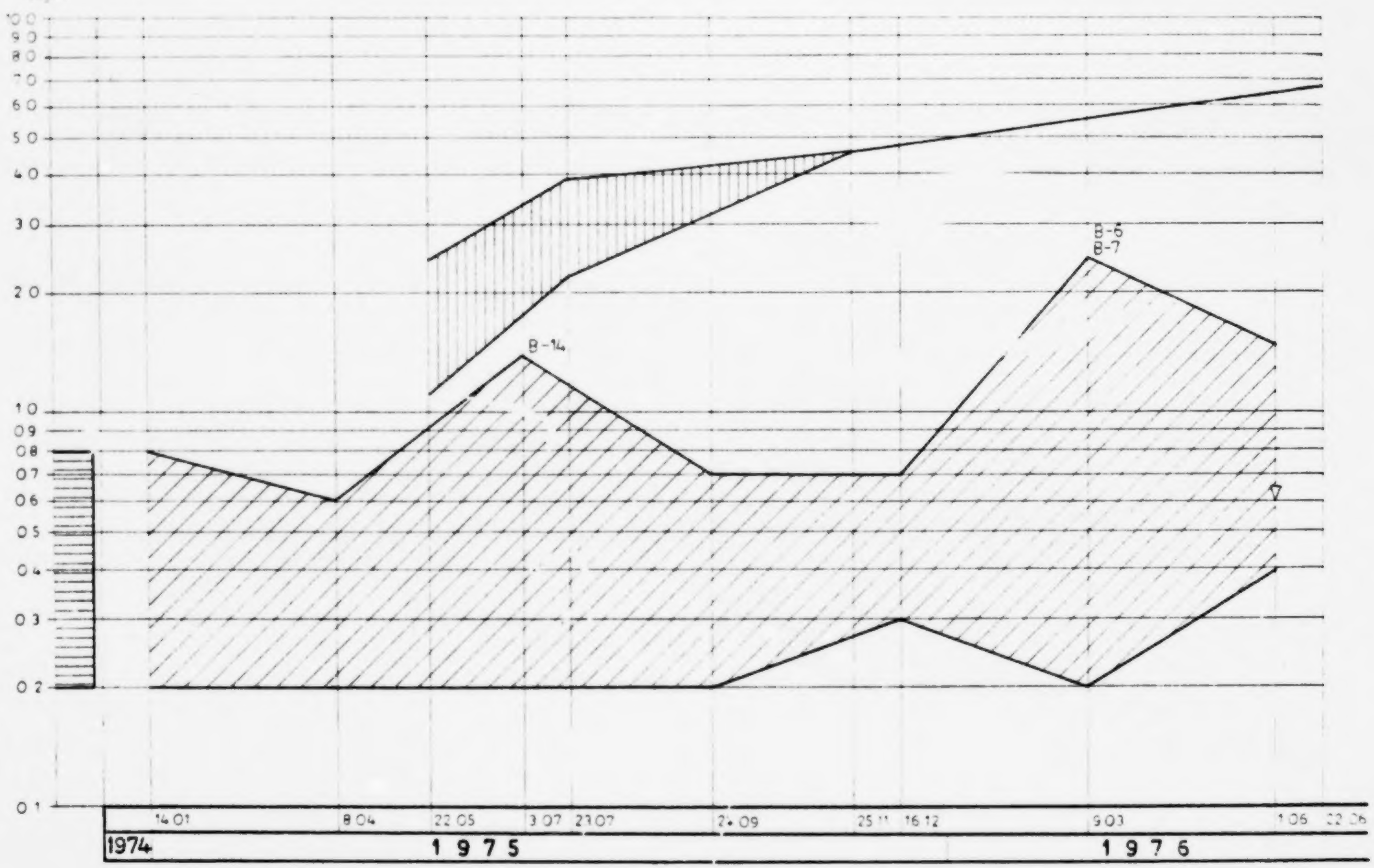


Fig. 66 DISPOSAL № 2. DIAGRAM OF Hg-ION CONTENT

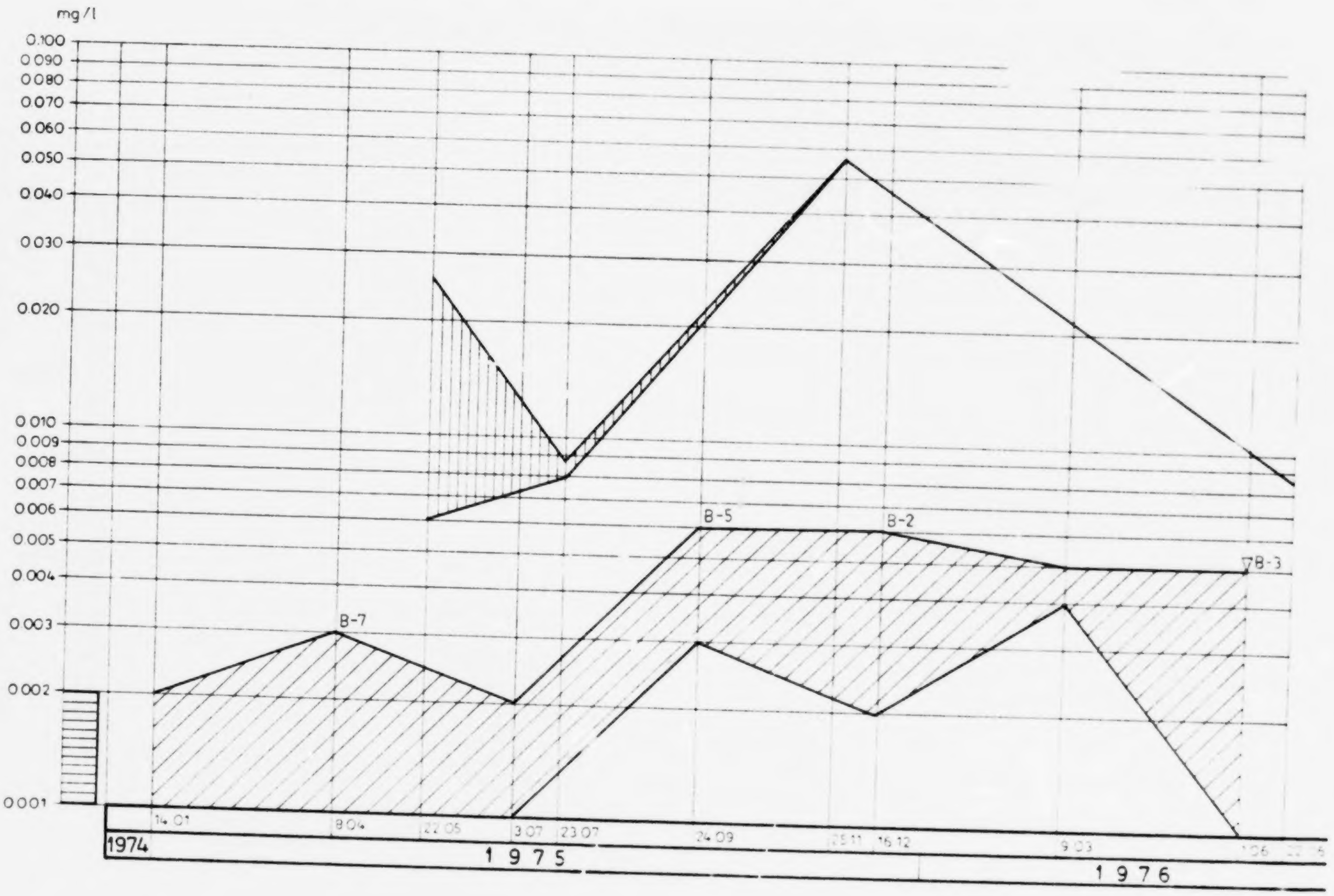


Fig. 67 DISPOSAL Nº 2. DIAGRAM OF Cd-ION CONTENT

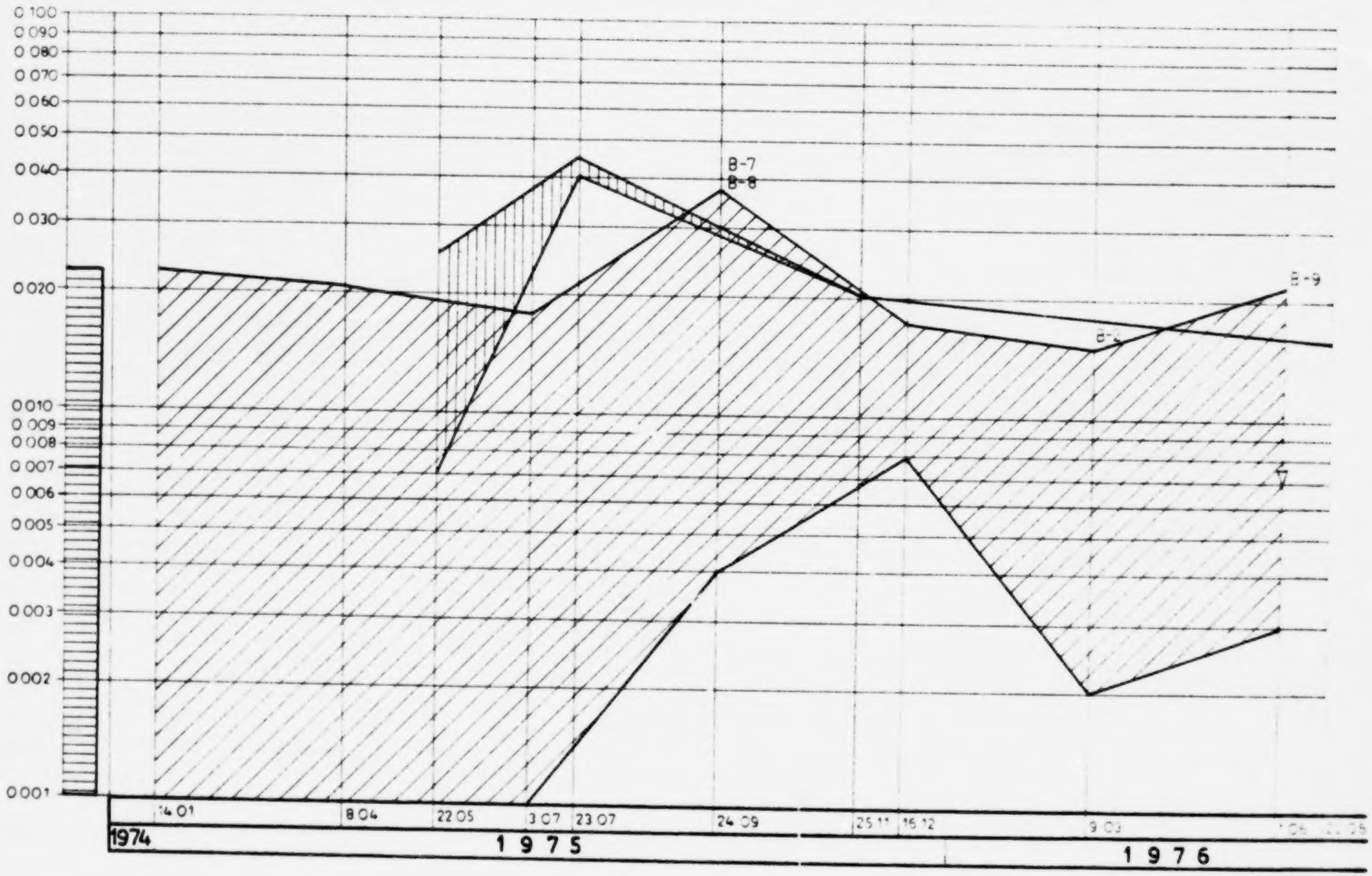


Fig. 68 DISPOSAL № 2. DIAGRAM OF Mo-ION CONTENT

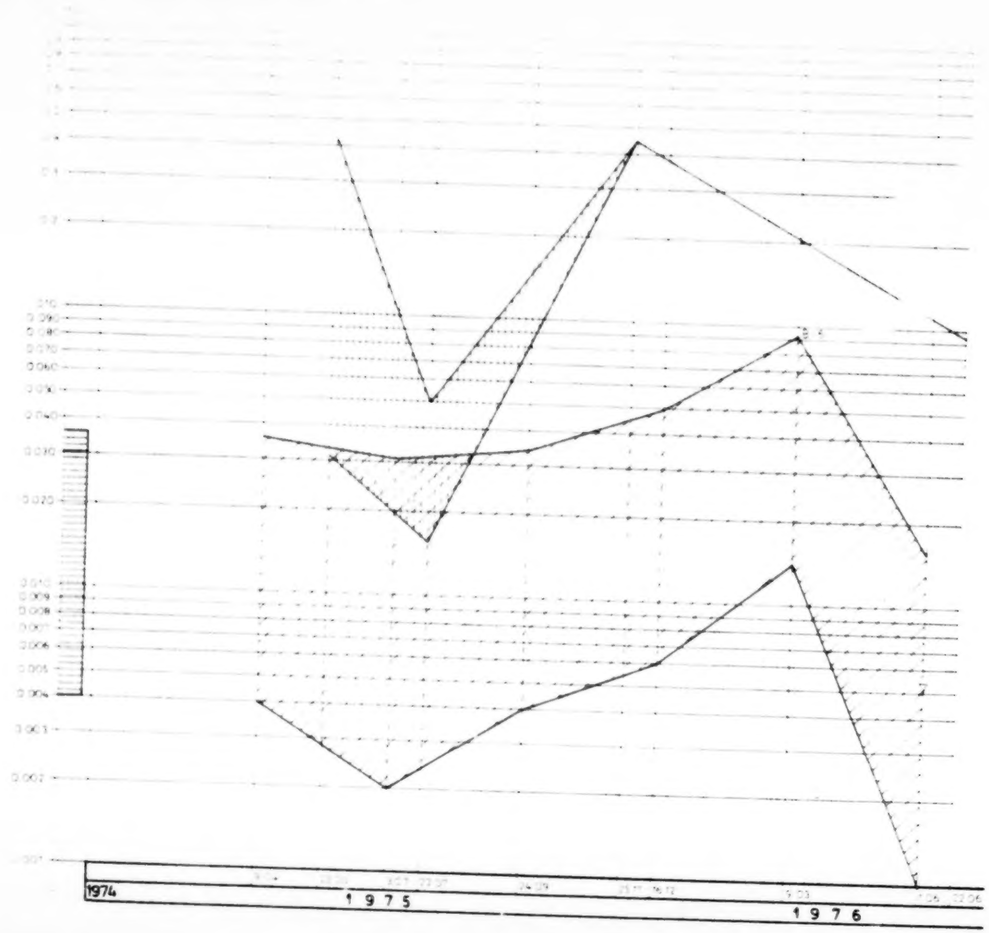


Fig.69 DISPOSAL № 2 DIAGRAM OF B-ION CONTENT

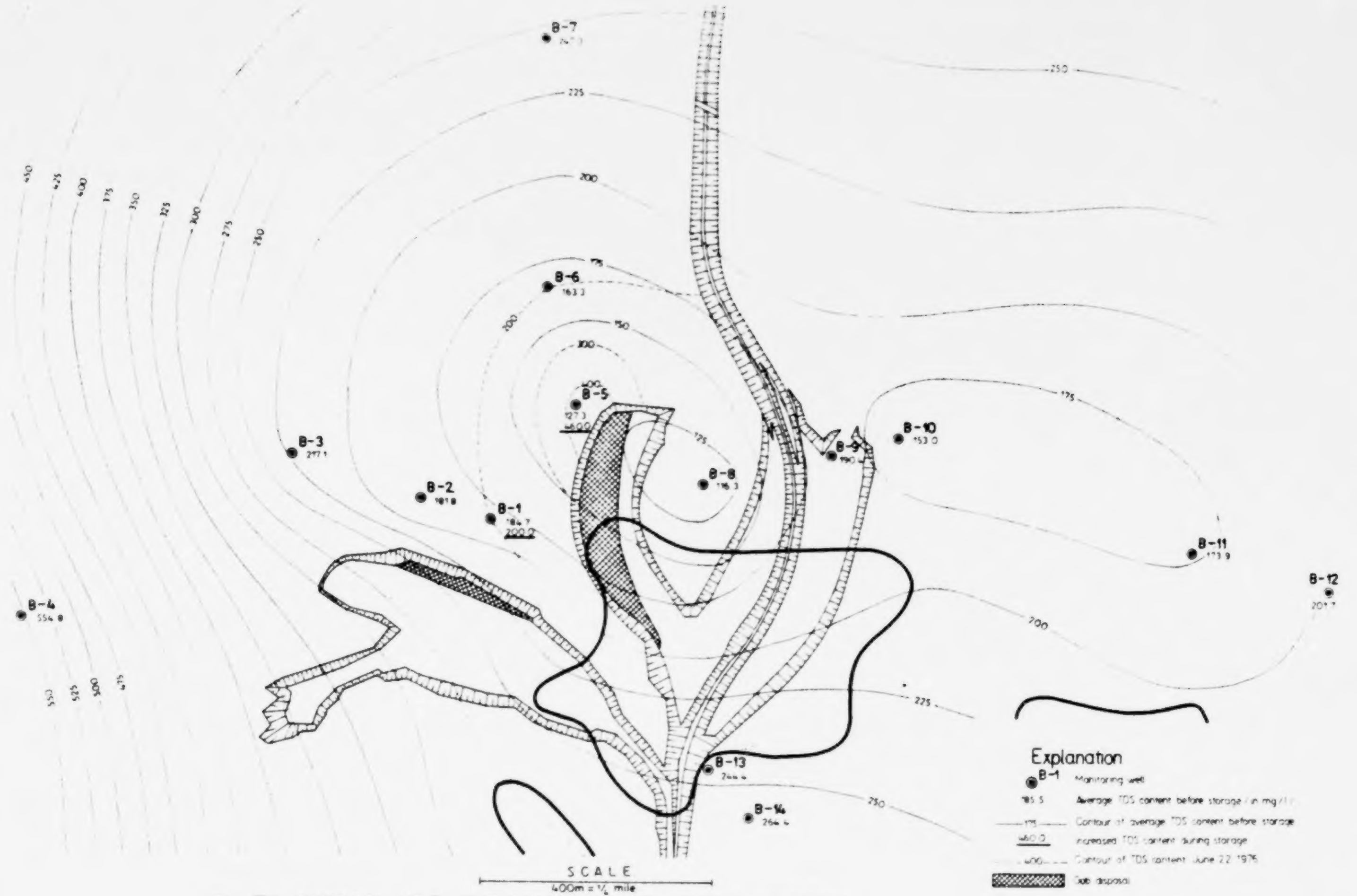


Fig. 70 DISPOSAL № 2. THE CONTOUR MAP OF TDS CONTENT

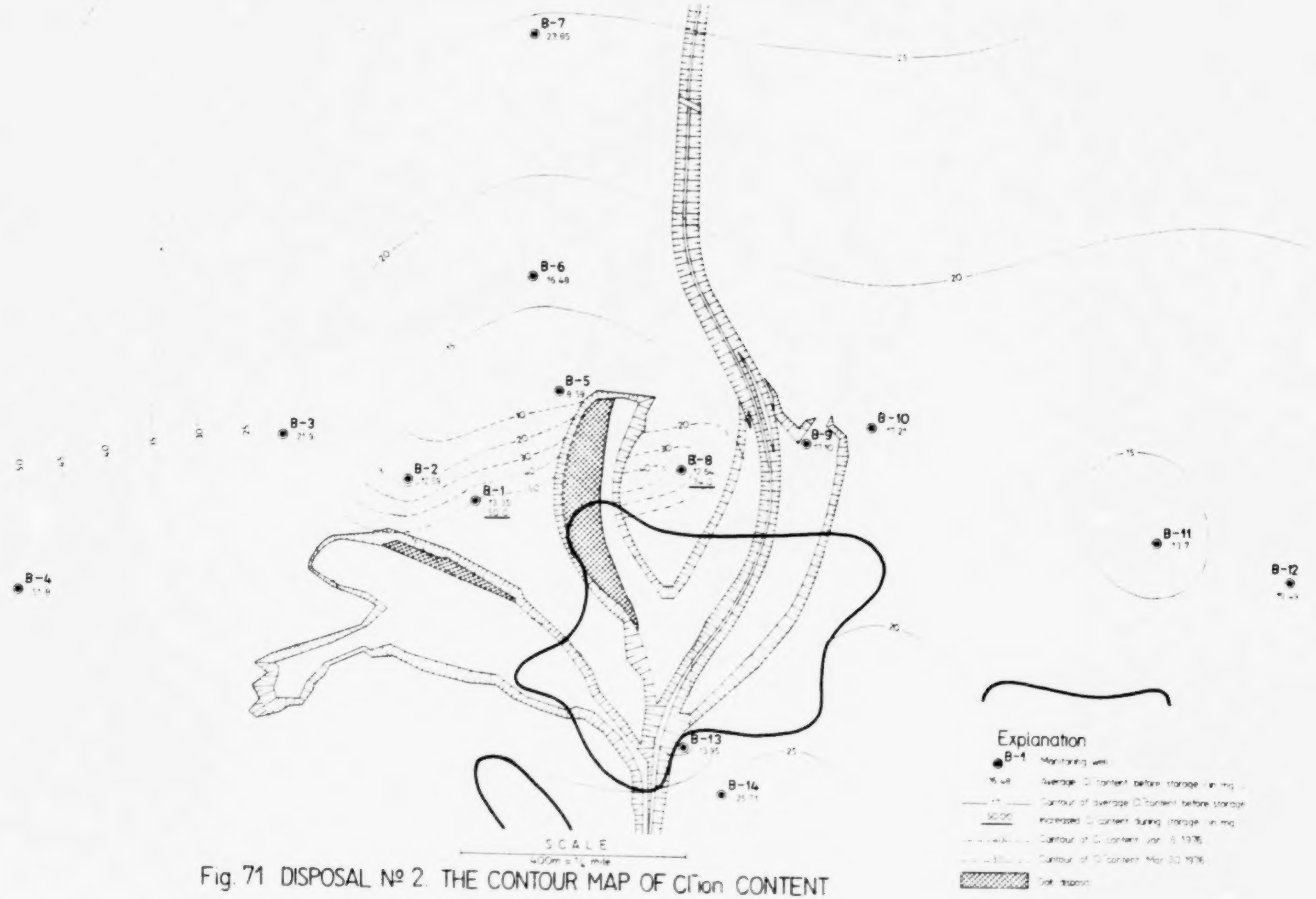

B-7
27.85
25
B-6
16.48
20
15
20
B-5
9.19
10
20
30
B-3
B-2
B-1
B-8
B-9
B-10
B-4
B-11
13.7
B-12
B-13
13.95
B-14
25.71
1
SCALE
400m = ¼ mile
Explanation
B-1 Monitoring well
16.48 Average Cl content before storage in mg
Contour of average Cl content before storage
50.00 Increased Cl content during storage in mg
Contour of Cl content Jan. 6 1976
Contour of Cl content Mar. 30 1976
Salt deposit

Fig. 71 DISPOSAL № 2. THE CONTOUR MAP OF Cl⁻ion CONTENT

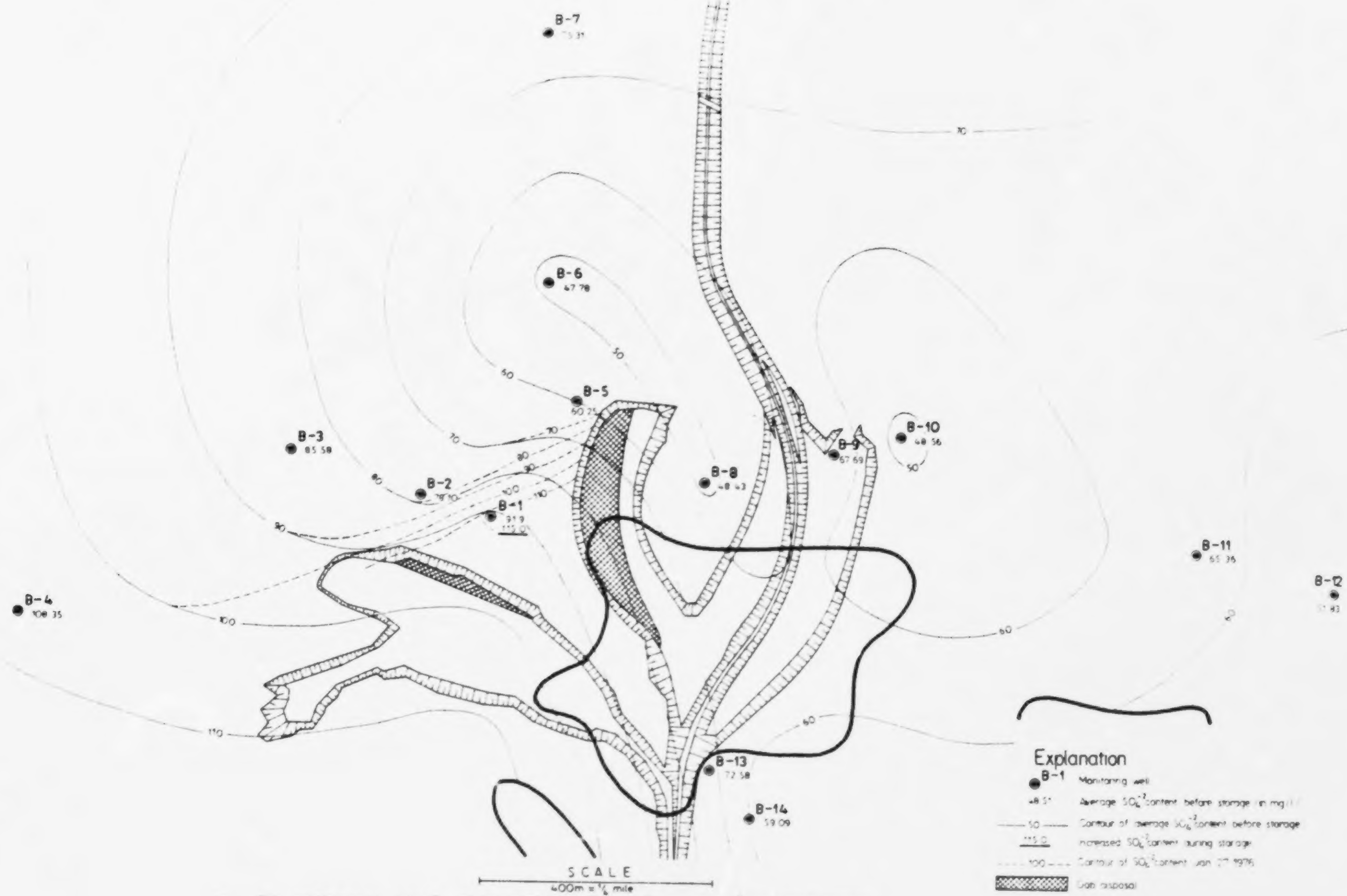

B-7
75.31
B-6
47.78
B-5
50.25
B-3
85.58
B-2
78.10
B-1
91.9
115.0
B-4
108.35
B-8
48.43
B-9
67.69
B-10
48.56
B-11
65.36
B-12
51.83
B-13
72.58
B-14
59.09
70
50
60
70
80
90
100
110
60
50
SCALE
400m = ¼ mile
Explanation
B-1 Monitoring well
48.51 Average SO_4^{-2} content before storage in mg/l
50 Contour of average SO_4^{-2} content before storage
115.0 Increased SO_4^{-2} content during storage
100 Contour of SO_4^{-2} content Jan 27 1976
▨ Gob disposal

Fig. 72 DISPOSAL № 2. THE CONTOUR MAP OF SO_4^{-2} ion CONTENT

CONCLUSIONS

1. Hydrogeological conditions in which the disposal is situated are characterized with very strongly diversified parameters of the waterlogged sand layer thickness and the hydraulic gradients.

2. The stored coal mining refuse (gob) consist of dry wastes coming from a construction of pits, rippings and from a dry separation and wet refuse coming from washers. Dry waste materials have as a rule large granulation and greater than 100 mm diameters and as such constitute much smaller danger because the leaching of toxic components from them is limited by small facial surfaces of contact with water. Washed waste material has smaller granulation commencing from dusty fraction and ending at a ϕ 50 mm granulation, and through greater comminution it is much more susceptible to leaching of soluble components.

3. Dry refuse because of its large sized granulation affords great difficulties in laboratory tests (in columns) and its comminuting would change the leaching ability in comparison with natural conditions. Washed refuse also affords difficulties in tests through washed out suspended solids and colloidal particles plugging the filter bed.

4. Performed investigations of the leachates acquired in optimum laboratory conditions for leaching particular components and the comparisons of these results with analyses of ground waters indicated, that a potential threat exists, through the increase in drinking quality water of the following components´contents:
   - increase in the pH reaction within limits of 2
   - increase in the conductivity of waters about 7 times
   - increase in the content of T.D.S. about 10 times
   - increase in the content of Cl ion to about 12 times
   - increase in the content of SO_4 ion to about 3 times
   - increase in the content of Na ion to about 55 times

- increase in the content of K ion to about 10 times
- increase in the content of Ca ion to about 5 times
- increase in the content of phenols to about 100 times
- increase in the content of Al ion to about 70 times
- increase in the content of Fe ion to about 3 times
- increase in the content of Mn ion to about 2 times
- increase in the content of Po_4 ion to about 10 times
- increase in the content of Cr ion to about 3 times
- increase in the content of Cd ion to about 10 times
- increase in the content of Cu ion to about 3 times
- increase in the content of Zn ion to about 10 times
- increase in the content of Hg ion to about 4 times
- increase in the content of Pb ion to about 10 times
- increase in the content of B ion to about 5 times.

The quoted above comparison does not point to a potential increase in ground waters of the Mg, As, CN, Sr and Mo ions. Speaks for this the fact, that the concentration of these ions in leachate was similar as in ground waters of the aquifer under study.

5. Independently of the tests of leachate performed in laboratory conditions, we collected during the last 3 months surface waters seeping through the disposal slopes, and in case of lack of such, from the pools standing on the disposal. These waters indicated a very different content of particular components in relation to laboratory leachate, and in relation to natural ground waters. A special attention deserves fact of a very high (often even exceeding the concentration in the laboratory leachate) content in these effluents of the Na, K and SO_4 ions. In the intermediate range are the TDS, the Cl, Mg and Ca ion contents. No clear increase of the heavy metals values was found, but so far one has at one´s disposal here only one series of analyses, and still to early is to draw final conclusions. Independently of the above phenomenon there is observed a great variability in the content of

particular components in various samples. This resulted by very different time of contact of gob with water. This time may vary within very large ranges, because the effluents are irregular and the waste material has a unequal granulation.

6. The storage of waste material commenced at the beginning of the year 1975, the intensity of the storing operation during the first four months was not great (total of about 27.000 m^3) in comparison with later period (30.000 - 40.000 m^3 monthly).
   Therefore practically looking at it, one has to consider that the storing actually began from April of 1975, and the observation period was only of 15 months.

7. The first occurrences of the disposal influence on the ground waters were observed at the beginning of the year 1976, therefore about a year after the commenced storage. These phenomena expressed themselves, in the appearances of highest concentration of particular ions in wells B-1, B-2, and B-5, while before the storage commencement these maxima were noted in wells B-3, B-9, and B-14. This rise in the pollution concentrations during the first 18 months of observations was small (20 %), but by a greater number of observations quite noticeable and agree with model prediction. Independently of the above small increase in concentration, observed was in some wells a flow of clearly increased waves of pollutants, and as an example of it can be:

- increase in the B-5 well of TDS content on the June 22, 1976 from average 250 to nearly 500 mg/l
- increased content of chlorides in well B-1 (from 25 to 50 mg/l) during days Jan. 1, 1976 and Mar. 30, 1976
- increased sulphate contents in B-1 well (from 80 to 120 mg/l) on the Jan. 27, 1976.

The above phenomena are occurring quite in a random fashion, which can however be easily explained, by irregularity of the precipitation and the effected through it a clear wave-wise occurrence of pollutants in ground waters. Particularly during the first period of observations this undulation was clearly noticeable, and by a 3 - weekly time intervals of water sampling not all of these waves could be recorded.

8. With disposals of large sizes the 18 months period of investigations is too short to draw adequate conclusions, therefore these observations should continue for at least 3 more years.

SECTION 8

REPORT OF MODEL TESTS

Parallel with the field investigations model tests were performed. The first their objective was to demontrate some aspects of the pollutants migration in the porous media-especially these which were not reflected in field tests and those regarding which less information was available in literature. These tests were performed on soil models, and on a slit type analogous Hele-Shaw type, coming from the point of view that often just simple demonstration of general tendencies is more persuasive than complicated mathematical proofs.

The second objective of the model research was a provision of pollution migration prognosis from the disposal no. 2 and its verification with actual state. These tests were performed on an EHDA model.

DEMONSTRATION TESTS PERFORMED ON THE SOIL MODELS

Two series of tests on the soil models were carried out in the framework of project.

First series carried out in the initial phase of project had for its object to demonstrate the course of pollutant propagation in porous medium, to show some hydraulic relations and to supplement observations drawn from field tests, and tests performed on anologous models.

For this series of tests the following brief assumptions were adopted:

- specific gravity of the polluted liquid γ = 1,022 G/cm^3 (in comparison to pure water accepted for the tests to be γ = 0,995 G/cm^3); $\Delta\gamma$ = 0,027 G/cm^3,

- occurrence of flow in a saturated porous medium with the permeability coefficient K_1 = 7.25 m/24 hrs and K_2 = 34,50 m/24 hrs, and on the boundory between the saturated zone and the zone of aeration - therefore in conditions most often encountered in the polish practice and anticipated in the field tests,

- hydraulic gradients within limits of I min = 0,035, I max = 0,2 and I = 0,

- variable feeding intensity with polluted liquid.

For the execution of tests an arrangement constructed was presented on the enclosed, fig. no. 73. This arrangement had dimensions 1000 x 700 x 150 mm and consisted of three chambers. Two of these were the water chambers with an arbitrarily controlled water table level for the reproduction of optional hydraulic heads. The main chamber was filled with a soil material and separated from the water chambers with a filter gauze. The front wall of the tank was made of organic glass for the purpose of a visual observation of the pollutant propagation in the medium. For the determination of the pollutant concentration the tank was equipped with 42 electric sensors distributed within the main chamber on a square grid 100 x 100 mm. From each sensor insulated wires were led to the control board.

The concentration of pollutants in a given point was measured on the basis of current intensity flowing between the sensor´s electrodes. The D.C. current used was from a battery, with voltage U = 5,7 V.
The soil medium chamber was filled with soil material, introduced into water in thin layers (5 cm), each time being compacted.

In tests of the pollutant propagation in the medium a normal school ink was used as the polluting substance. Selection of this type of pollutant was dictated by the consideration of its characteristics:

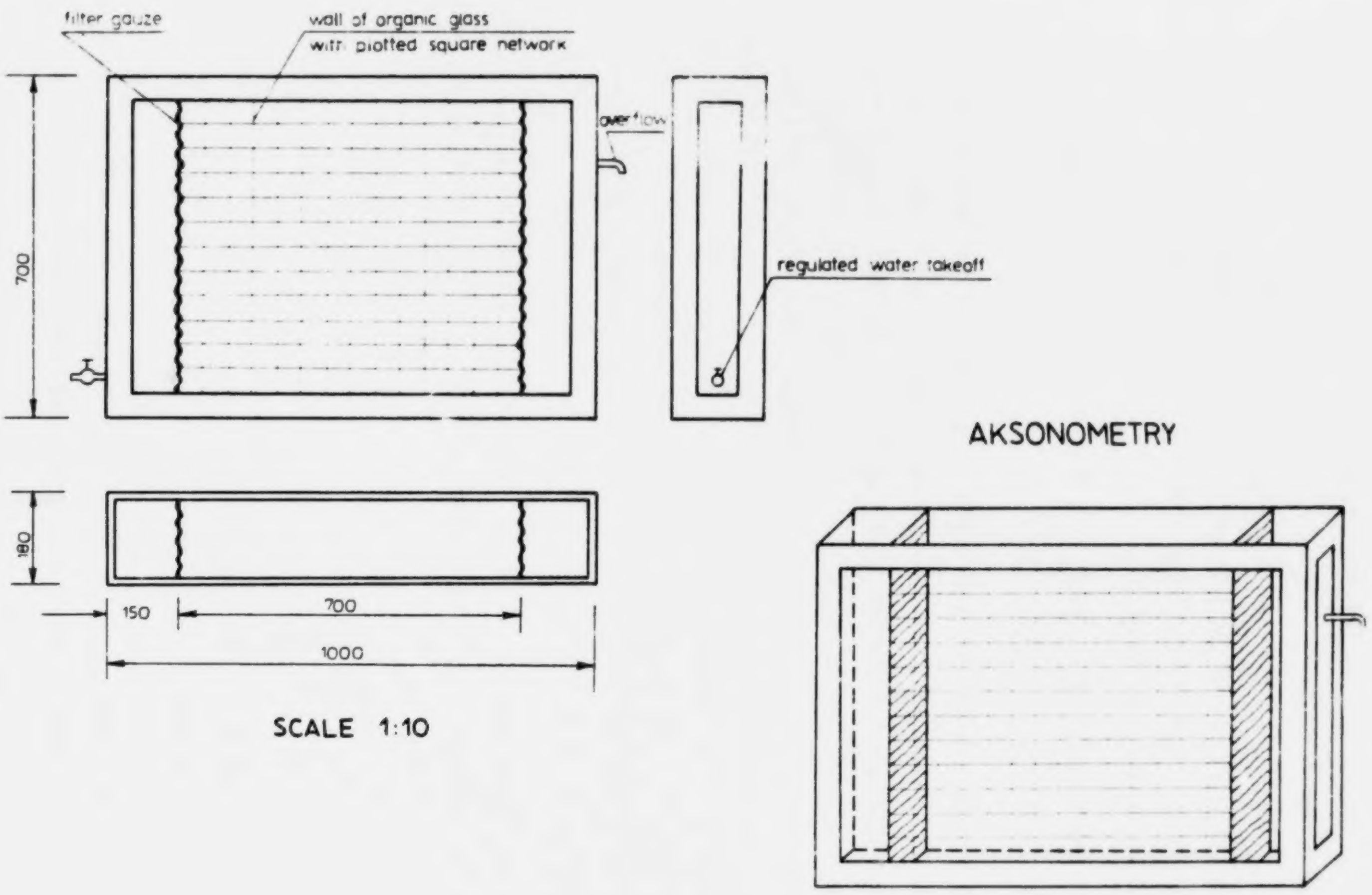


Fig. 73 Scheme of ground model for first series of demonstration

- density equal to 1,022 g/cm^3
- viscosity equal to water viscosity
- miscibility with water
- color, permitting a visual observation of occurrence
- with the employed sensors and the DC current voltage the relationship between the water and ink mixture concentration, and the current intensity is linear
- current intensity with applied voltage does not change in time for a given mixture concentration.

With these characteristics the ink has shown itself to be the best type of pollutant. The pollutant was brought into the tank on its whole width. The propagation of the pollutant was observed on the front, transparent wall of the main chamber (visual observation of occurrence), and electric measurements performed at time intervals from 10 mins (for conditions in which the progress in propagation was fast), to 1 hr (for conditions of a slow variation). Some informative observations of the above quoted tests are presented on the enclosed pictures (fig. 73 to 85). In this place these will be discussed in relevance to conclusions, illustrated with appropriate material.

For the soil medium with the filtration coefficient K_1 = 7,25 m/24 hrs=0,0084 cm/sec, the tests were carried out by four actual velocities of water flow:

V_1 = 0,0 cm/sec.

V_2 = 0,0011 cm/sec.

V_3 = 0,0017 cm/sec.

V_4 = 0,00563 cm/sec.

In all tests performed on this soil medium the pollutants were applied with similar intensity, Q = 0,14 cm^3/sec.

For the soil medium with the coefficient of filtration K_2 = 34,5 m/24 hrs = 0,0412 cm/sec., the tests were performed by varying, velocities, and also by varied intensity of the pollutants charge:

And so by:

V_1 = 0,0 cm/sec.	Q_1 = 0,14 cm^3/sec.
V_2 = 0,0018 cm/sec.	Q_2 = 0,16 cm^3/sec.
V_2 = 0,0018 cm/sec.	Q_3 = 0,01 cm^3/sec.
V_3 = 0,0035 cm/sec.	Q_2 = 0,16 cm^3/sec.
V_4 = 0,04 cm/sec.	Q_1 = 0,14 cm^3/sec.

Employing by the same V_2 flow velocity a different intensity of pollutant delivery the Q_2 and Q_3, and by the same intensity of pollutants Q_2 different velocities V_2 and V_3 acquired were data allowing to draw comparable conclusions.

The first conclusions arrived at from the analysis of these tests is a conclusion of a methodological nature. Namely, the effect visually observed on the front glass wall of the model reproducing with its shape preceded in time the true flow of pollutants in porous medium. It is the result of smaller hydraulic resistance exerted on the glass panel by about 70 - 100 % for formations with the K_1 = 7,25 m/24 hrs. It was almost equal to the true occurrence with the K_2 = 34,50 m/24 hrs soil.

For the velocity $V_1 = 0$ $(I = 0)$ the pollutants migrate downwards under the influence of gravity. In horizontal direction under the influence of a certain hydrostatic over pressure (resulting from filtration resistances of the soil medium in the bottom of hollow, to which liquid is supplied in surplus), and also of the disperssion and diffusion forces. It is assumed in the following considerations, that the front of the pollutants' displacement is a front of their 75 - 90 % concentration on the other hand, the zone of pollutant concentration of the 10-75 % value is considered as a zone of mixing.

The velocity of a vertical displacement of pollutants is shown on the enclosed diagram (fig. no. 86).

From the above diagram appears clearly, that the velocity of vertical migration of pollutants decreases in time. Therefore and with depth, this slowing down value after the period of the first 6 hours depends on the value of the filtration coefficient.

During the first 6 hours the front of pollutants moved for both types of soil material by about 15 cm. During the next 18 hours the curves separate. One can state generally, that with about a 5 times greater coefficient of filtration, the velocity of vertical displacement of the pollutant front is 2 times greater. This is illustrated on the diagram, fig. no. 87.

The velocity of vertical migration of the pollution front depends also on the stability of the position of this front in relation to the horizon of pollutants delivery. Respective relationships are illustrated on the diagram, fig. no. 88.

Examining the horizontal spreading of the pollutants it may be said that:

- for the soil with a permeability coefficient K = 7,25 m/24 hrs = = 0,0084 cm/sec., the width of the polluted zone is constant, and regardless of the depth of the migration front in vertical, was about 18 cm,

- for the soil with the permeability coefficient K = 34,5 m/24 hrs = = 0,0413 cm/sec. the width of the polluted zone changes in dependence on its vertical dimensions. This relation illustrates the next diagram, fig. no. 89.

The width of the zone of mixing in the observed time (to 24 hrs) remains almost constant in time and for various experiments it fluctuated within the 6 to 15 cm limits.

Further tests were carried out with a variable velocity $(v \neq o)$ of ground water flow in porous medium. For the soil material with a permeability coefficient K = 7,25 m/24 hrs = 0,0084 cm/sec., the following observations were made.

Shape and position of the front of pollution is clearly dependent on the velocity of the water flow.

By small velocities the participation of the vertical vector of gravitation is considerably greater. And so for instance when after the six hours by an actual ground water flow velocity v = 0,0011 cm/sec., the depth of the pollution front was 20 cm, then by the velocity of v = 0,0017 cm/sec. this just 12 cm, and by velocity of v = 0,0056 was only 3 cm. The above tendencies can be demonstrated in a form of diagram (fig. no. 90).

By velocities different from zero the zone of pollution is being confined underneath and on the side of the inflowing water, not changing in time the boundary surface. Inclination of this surface in relation to the horizon is a function of flow velocity, where the angle of the inclination is getting smaller with increased velocity. By greater velocities the zone of a strong concentration of pollution can be found on a small depth under the soil surface - the "tongue" of the pollution is narrow and elongated. By small velocities the zone of strong concentration of pollutants draws deeper.

The width of the zone of mixing (in which the phenomena of dispersion and diffusion are occurring)is clearly variable in different directions. The narrowest (within 6 cm) and a non - variable in time is from the side of the inflowing water, which is an effect of interaction of cancelling themselves vectors of velocity, and dispersion-diffusion. From the practical point of view this does not depend on the actual velocity of the water flow.

In the vertical direction this changes within a small range from 6 cm by the lowest velocities, to 4 cm by the highest velocities. As appears, it does not depend on the time factor.

Differences are present in the course of the pollutant migration along the direction of ground water flow. One can observe here a clear relationship between the width of the zone of mixing and both the time (increase) and the flow velocity. By smaller flow velocities this zone is wider.

Striking is the fact, that the displacement of pollutants takes place both in the zone of capillary rise, and in the saturated zone, where the speed of migration in the capillary is over two times less than in the saturated zone.

For the soil with a permeability coefficient K = 34,5 m/24 hrs. the tests confirmed the observations made for the soil with the coefficient K = 7,25 m/24 hrs.

A very essential conclusion from these tests is also the ascertainment of a very pronounced relationship existing between the shape of the polluted area and the intensity of the pollutants delivery.

In conditions where the amount of introduced pollutants amounts to Q = 0,01 cm^3/sec., the "tongue" of pollutants has a shape of an elongated ellipse with the ratio of longer to shorter axis about 4:1, which is sliding on the surface of the ground water table both in the capillary and in the saturated zone. When the quantity of delivered pollutants increased 16 times (Q = 0,16 cm^3/sec.) the share of vertical migration was much greater. See diagram (fig. no. 91).

The zone of pollution has in this case also a correspondingly greater surface, whereby the increase of a horizontal reach does not exceed 10 %, and the vertical is about 10 times greater. The volume of the pollutted zone is therefore about 10 to 12 times greater. Moreover, the tests on a medium less permeable have shown that by the same actual velocity (being a function of smaller hydraulic head in relation to a medium less permeable), the pollutants penetrate downwards 2 times faster, when the medium permeability is 5 times greater, whereas the horizontal penetration has an approximated velocity. This occurrence illustrates the diagram (fig. no. 92).

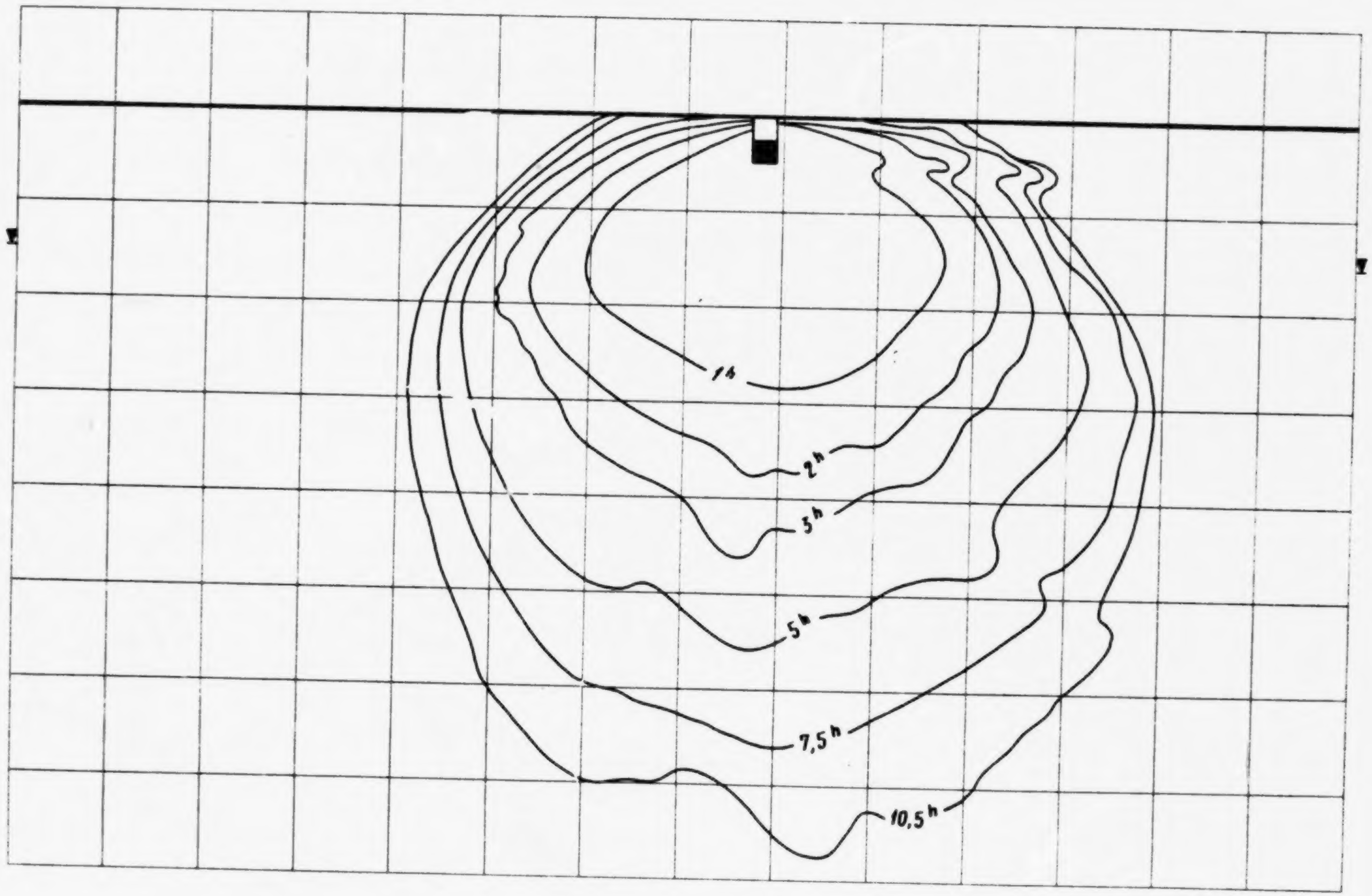


Fig. 74 Visuality of pollutants migration v = 0,0cm/s, k=0,0412 cm/s ; Q=0,10ccm/s

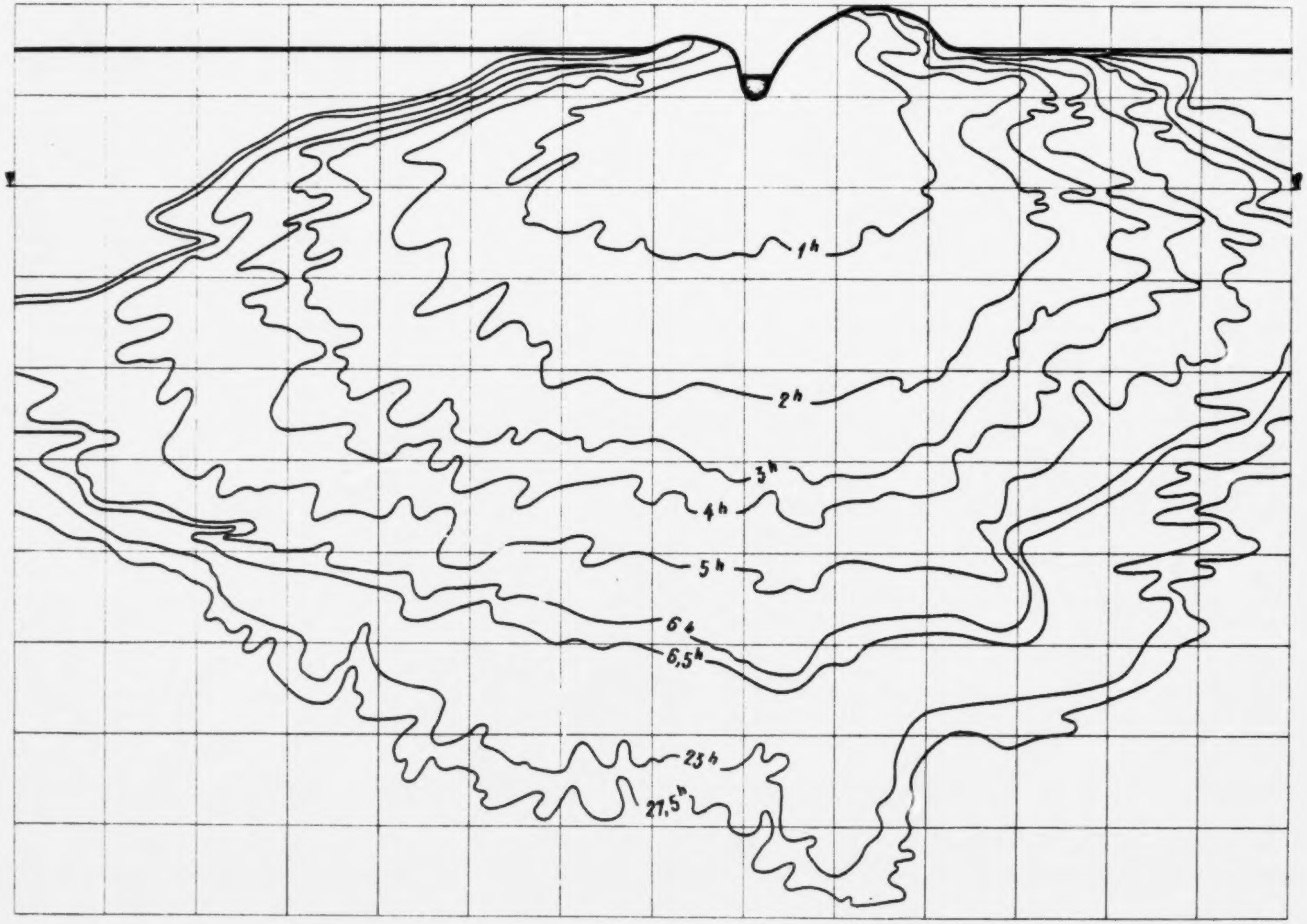


Fig. 75 Visuality of pollutants migration v=0,0cm/s; k=0,0084cm/s; Q=0,14ccm/s

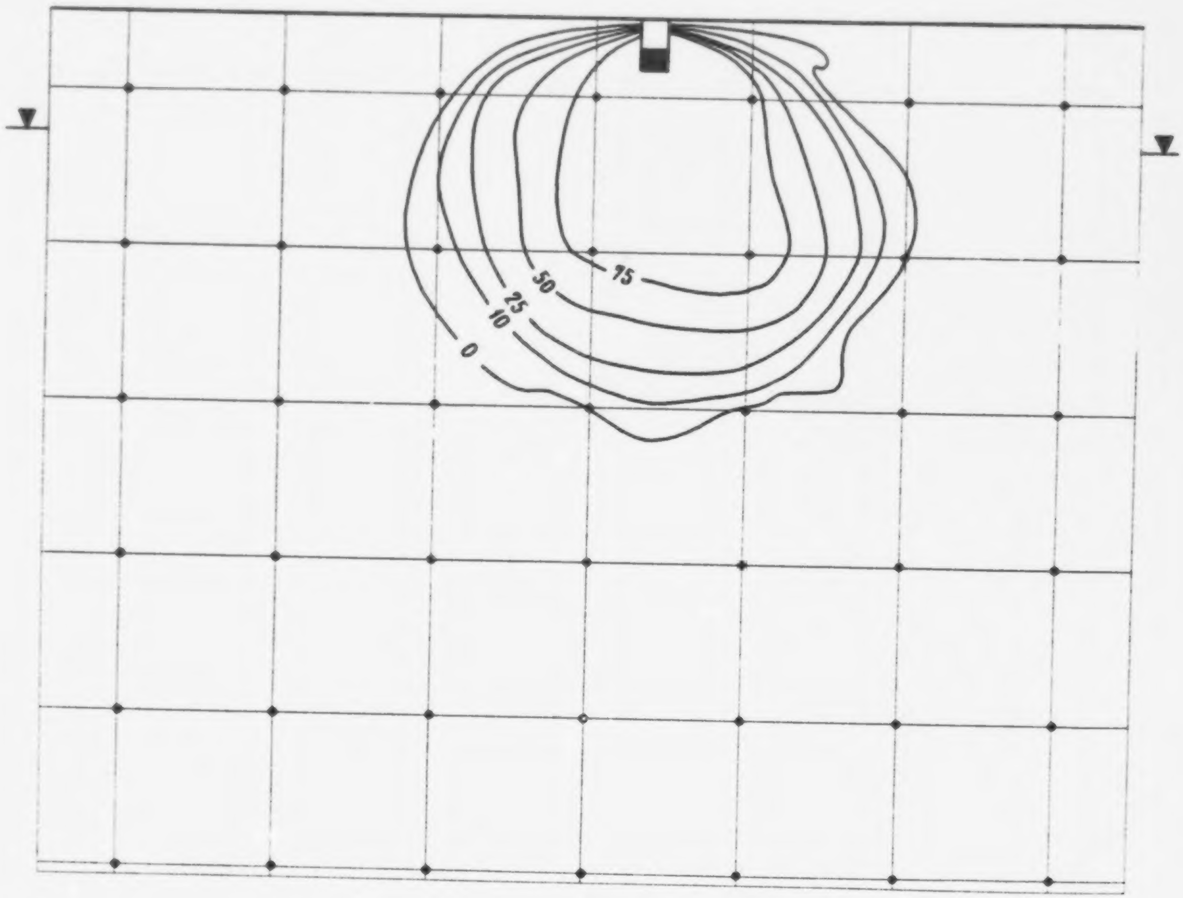


Fig. 76 Distribution of pollutants concentration after 5^h k=0,0412cm/s; v=0,0cm/s; Q=0,10ccm/s

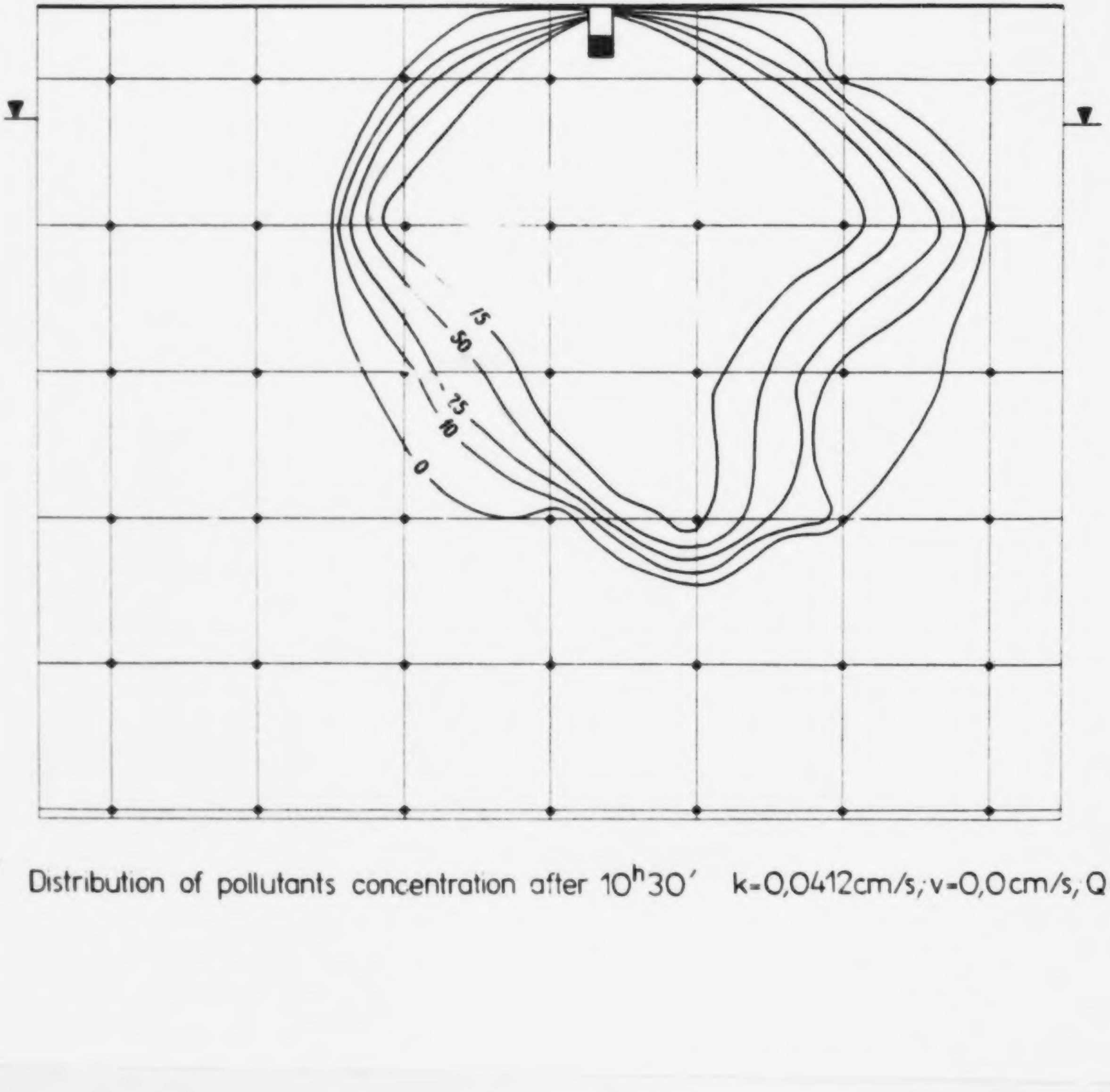


Fig. 77 Distribution of pollutants concentration after $10^h30'$ k=0,0412cm/s; v=0,0cm/s; Q=0,10ccm/s

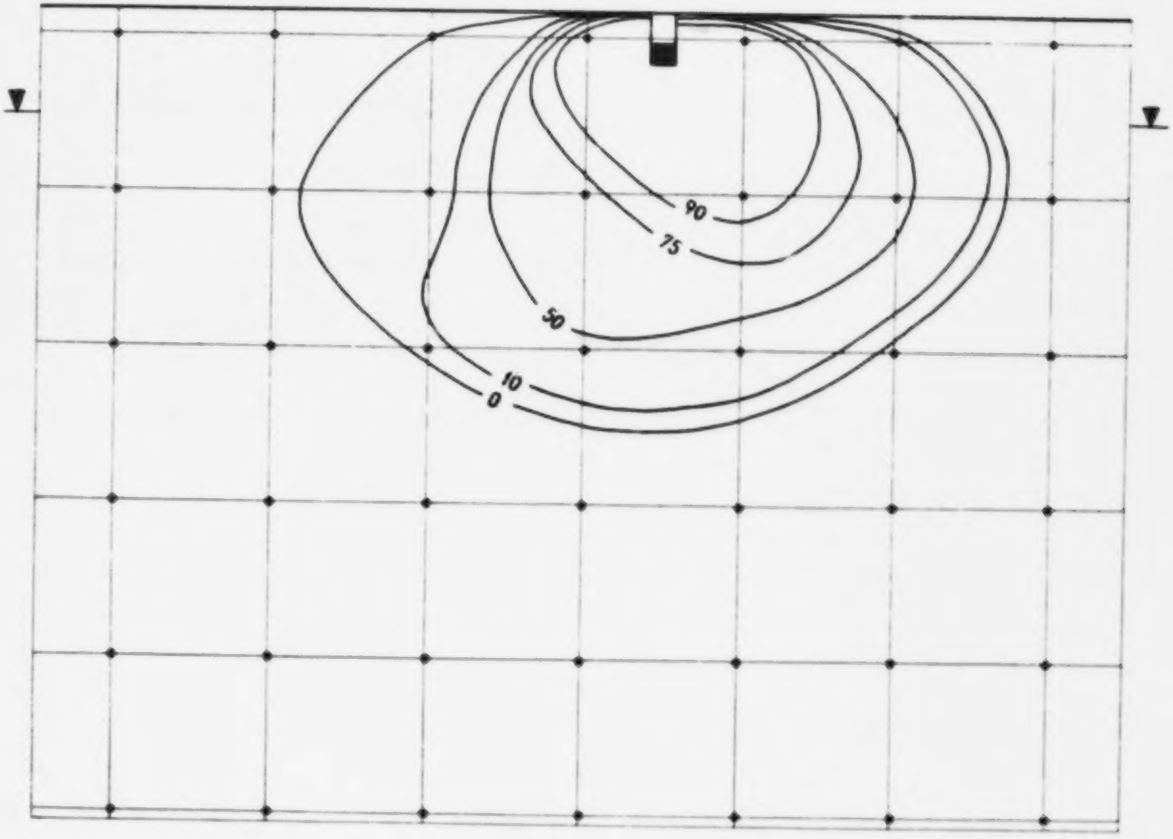


Fig. 78 Distribution of pollutants concentration after 5^h k=0,0084cm/s; v=0,0cm/s; Q=0,14ccm/s

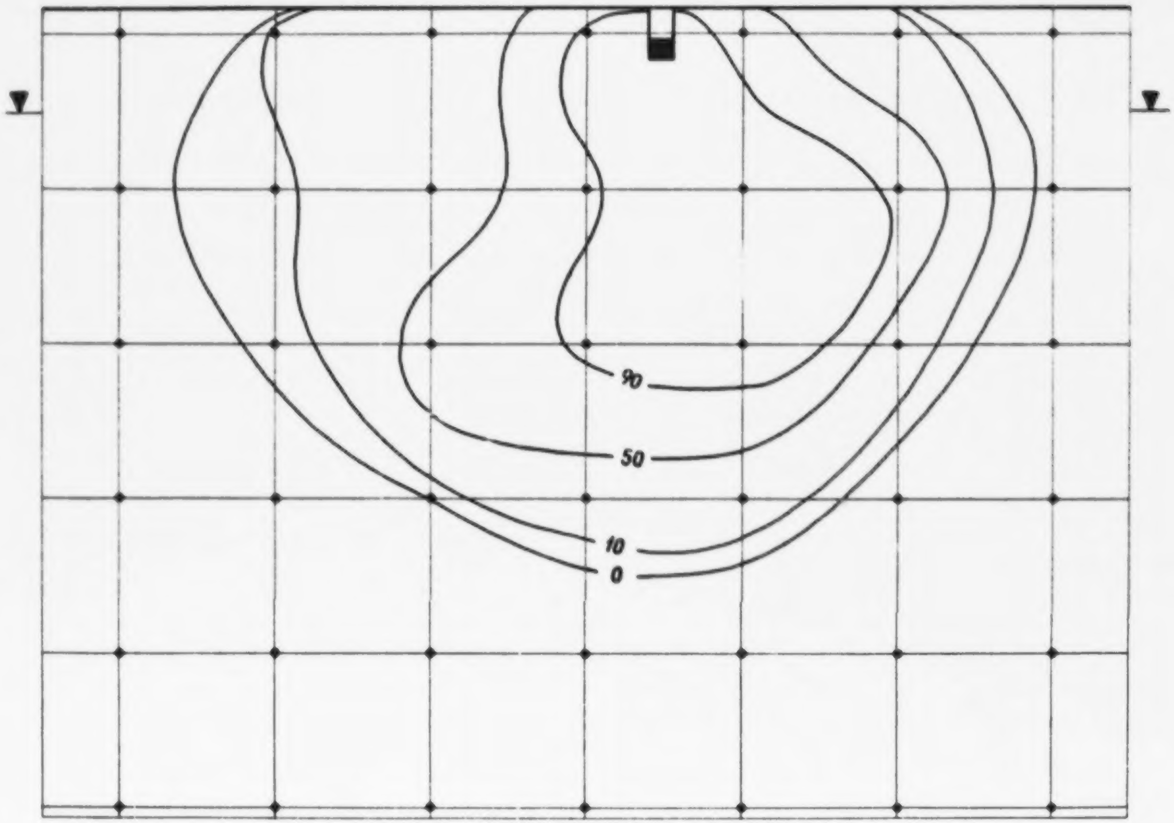


Fig. 79 Distribution of pollutants concentration after 24^h k=0,0084cm/s; v=0,0cm/s; Q=0,14ccm/s

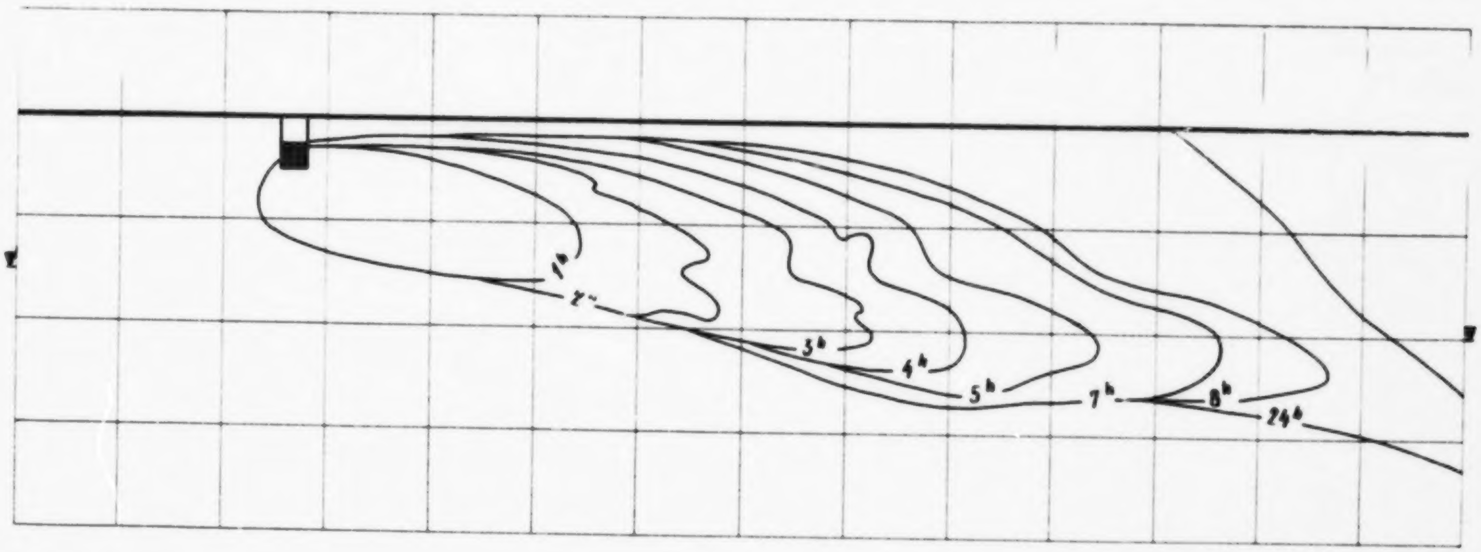


Fig. 80 Visuality of pollutants migration k = 0,0412cm/s; v = 0,0018cm/s; Q = 0,01ccm/s

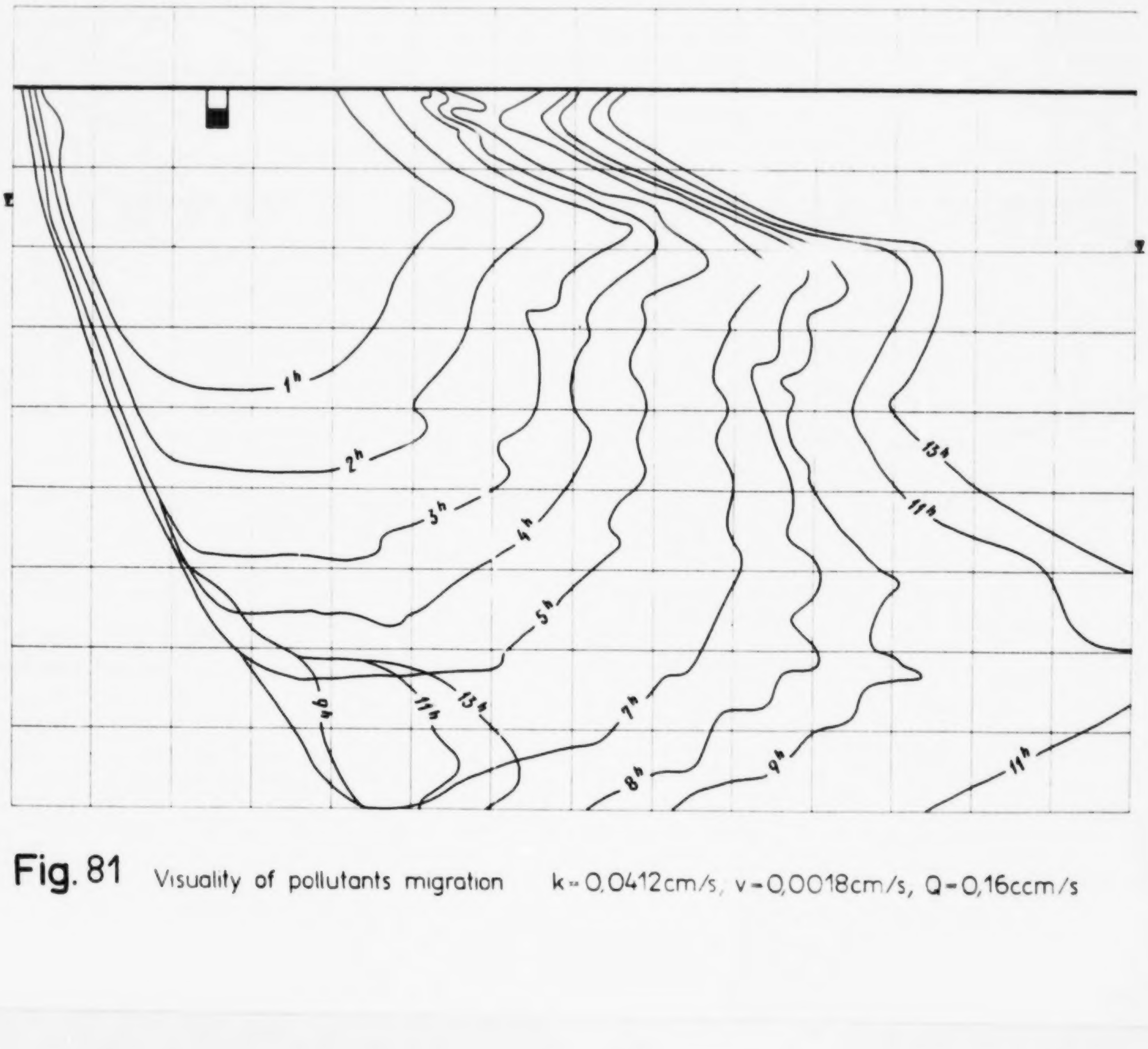


Fig. 81 Visuality of pollutants migration $k = 0{,}0412$ cm/s, $v = 0{,}0018$ cm/s, $Q = 0{,}16$ ccm/s

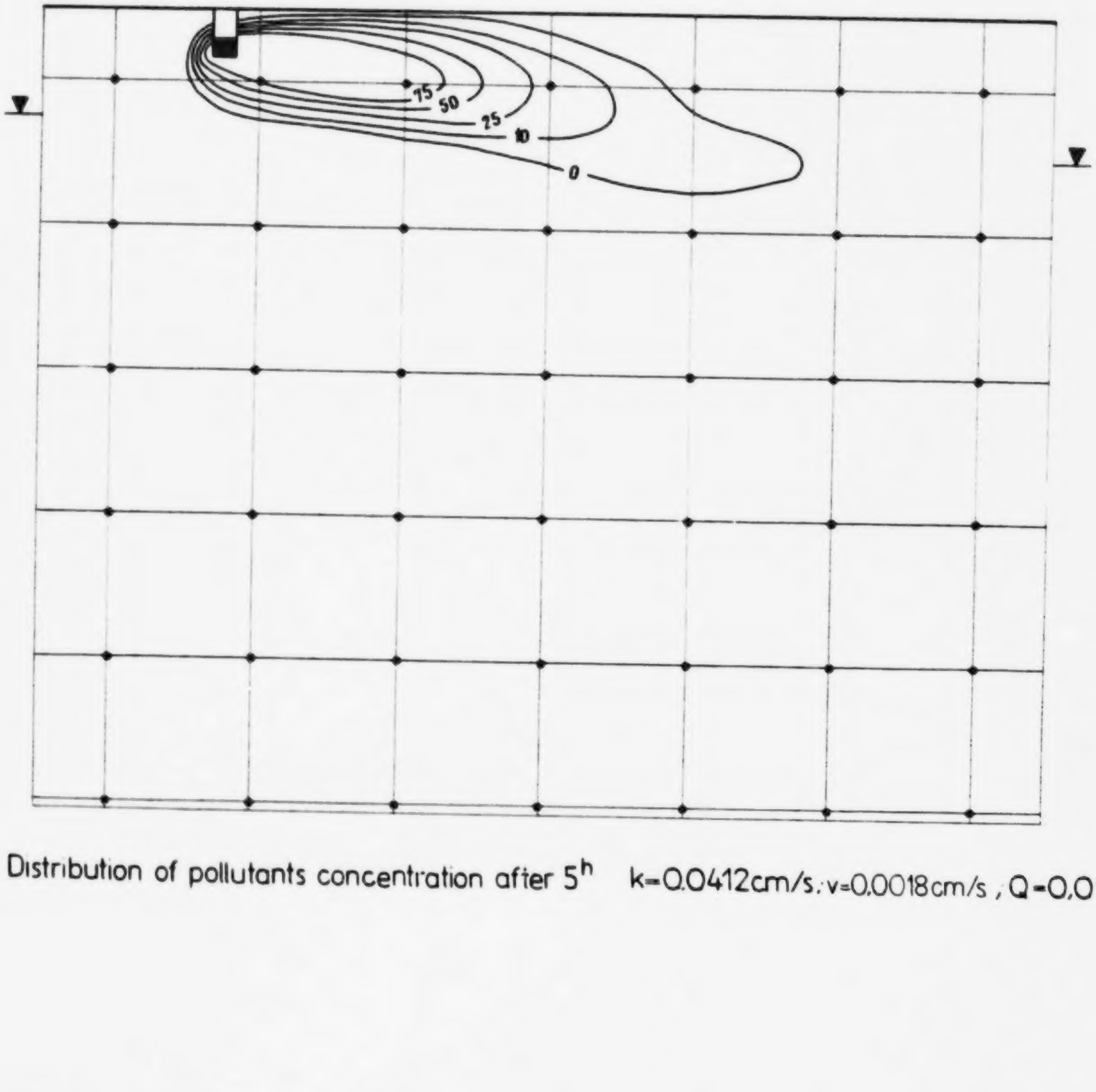


Fig. 82 Distribution of pollutants concentration after 5^h k=0.0412cm/s; v=0.0018cm/s , Q=0.01ccm/s

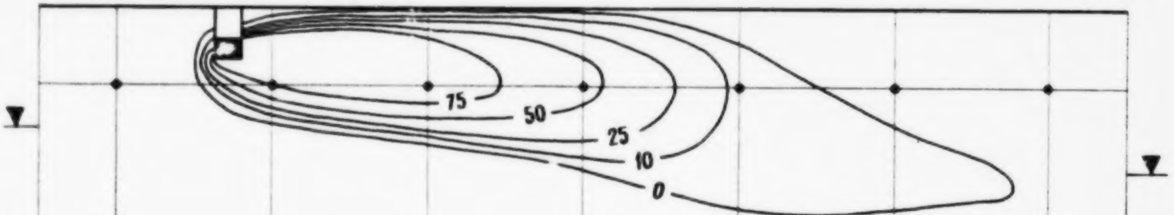


Fig. 83 Distribution of pollutants concentrction after 8^h k=0,0412cm/s, v=0,0018cm/s ; Q=0,01ccm/s

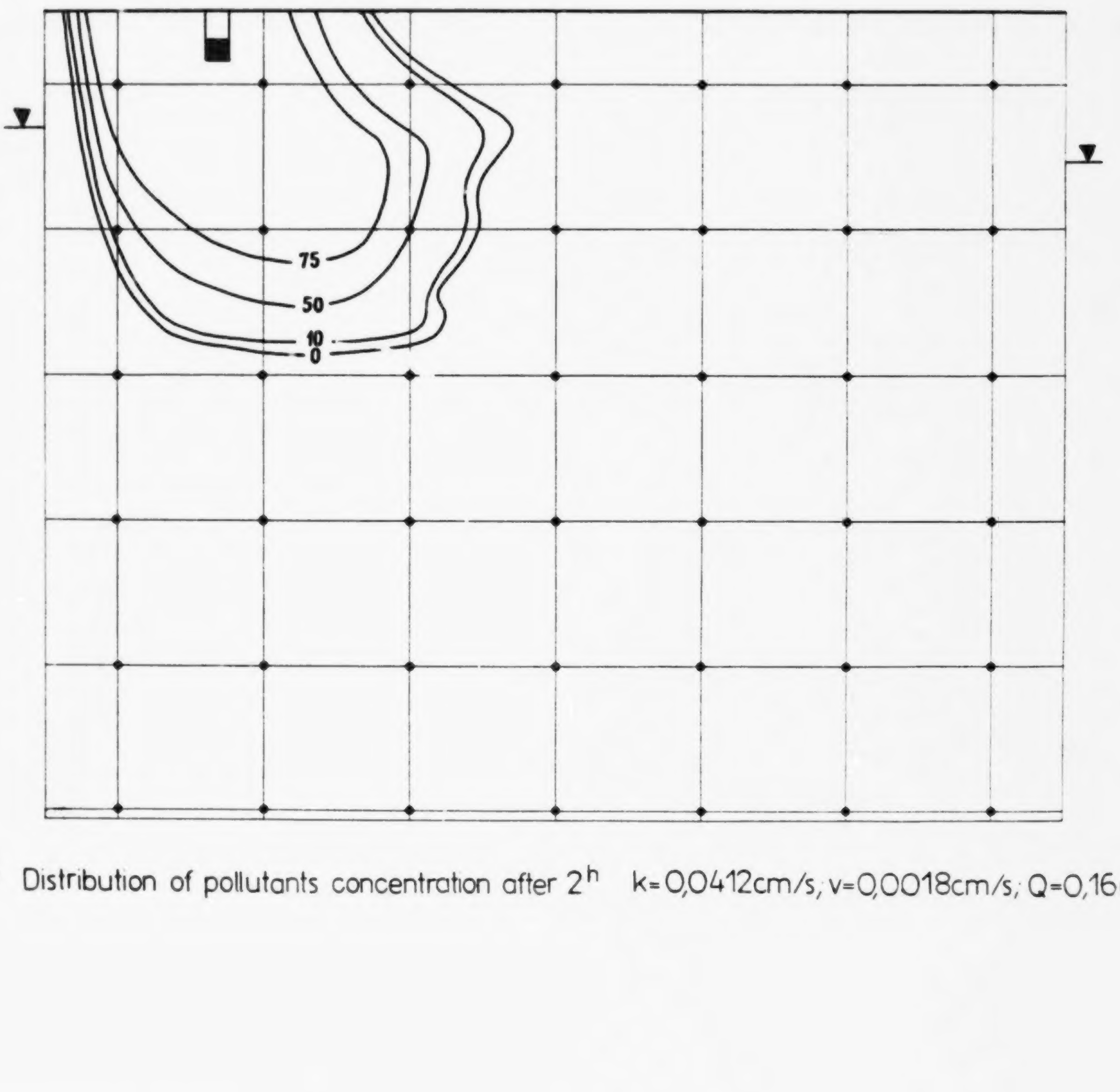


Fig. 84 Distribution of pollutants concentration after 2^h k=0,0412cm/s; v=0,0018cm/s; Q=0,16ccm/s

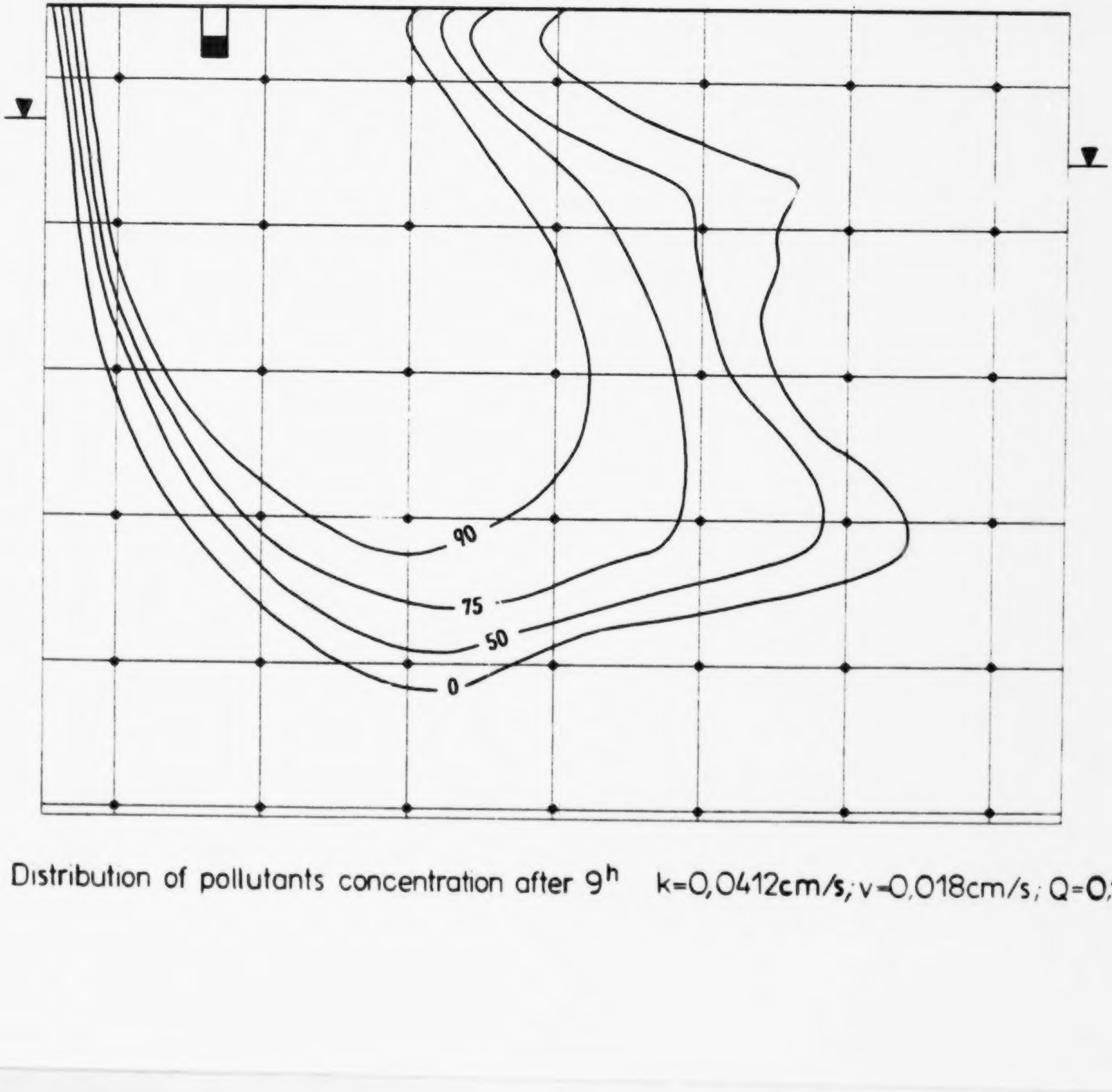


Fig.85 Distribution of pollutants concentration after 9^h k=0,0412cm/s; v=0,018cm/s; Q=0,16ccm/s

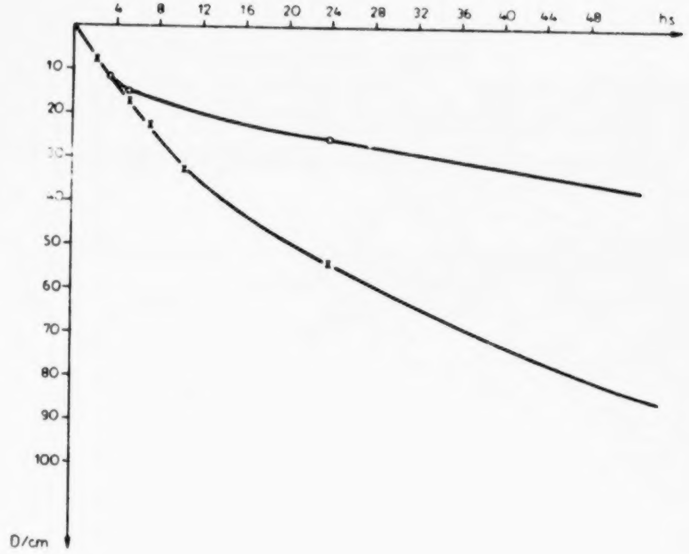


Fig. 86 Diagram of relation between polluted front vertical range and time $\Delta\gamma = 0.027 G/cm^3$

V - 0 I - 0

o o for k = 0.0084 cm/sec = 7.26 m/24h

x x for k = 0.0412 cm/sec = 34.5 m/24h

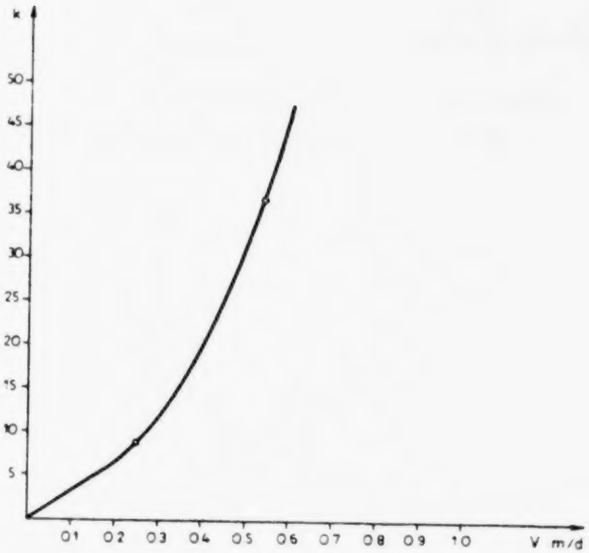


Fig. 87 Diagram of relation of vertical migration velocity and coefficient of permeability

V - 0 I - 0

$\Delta\gamma = 0.027 G/cm^3$

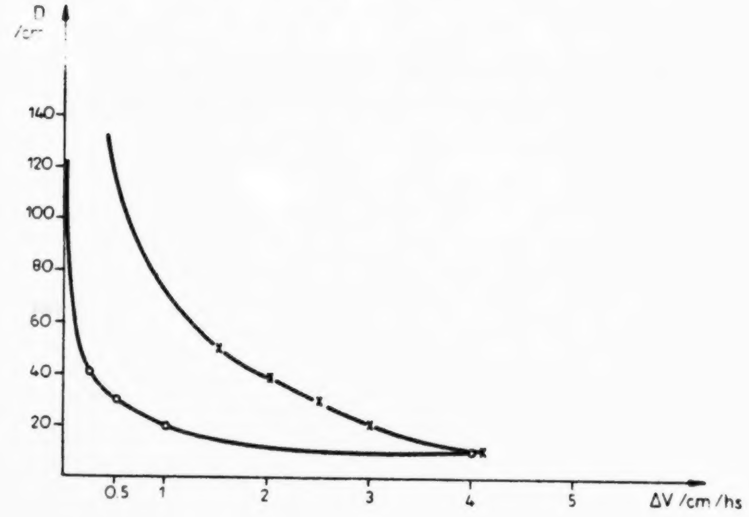


Fig. 88 Diagram of relation between velocity of polluted front migration and depth

V=0 I=0 $\Delta\gamma = 0.027 G/cm^3$

o o for soil k = 7.25 m/d

x x for soil k = 34.5 m/d

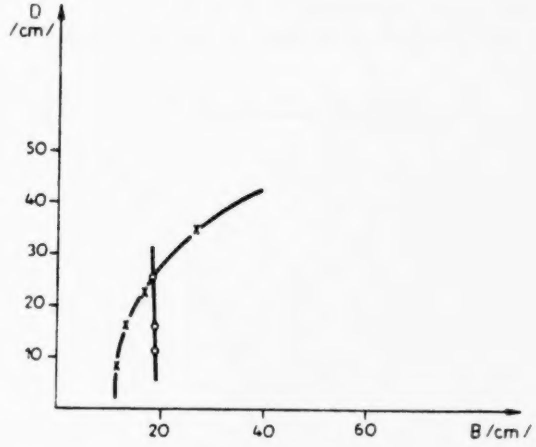


Fig. 89 Diagram of relations between vertical and horizontal dimensions of polluted zone

V=0 I=0 $\Delta\gamma = 0.027 G/cm^3$

o o for k=0.0084 cm/sec = 7.25 m/24h

x x for k=0.0412 cm/sec = 34.5 m/24h

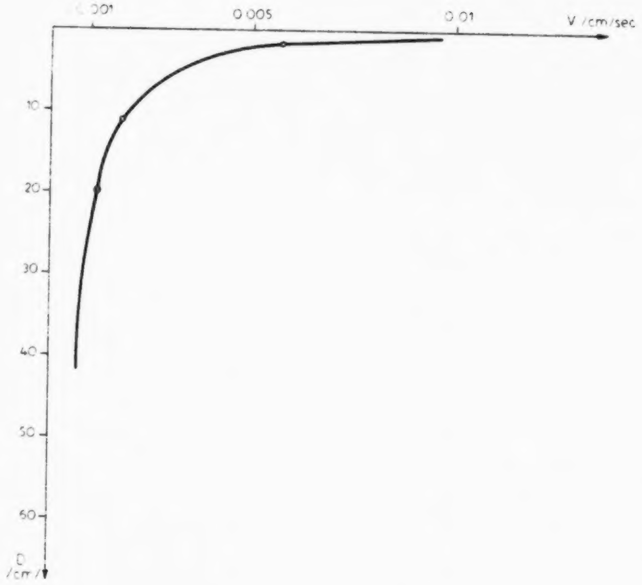


Fig. 90 Diagram of relation between polluted front depth and actual velocity of filtration for soil k=0.0084cm/s after 6 hs of its migration

$\Delta\gamma = 0.027 G/cm^3$

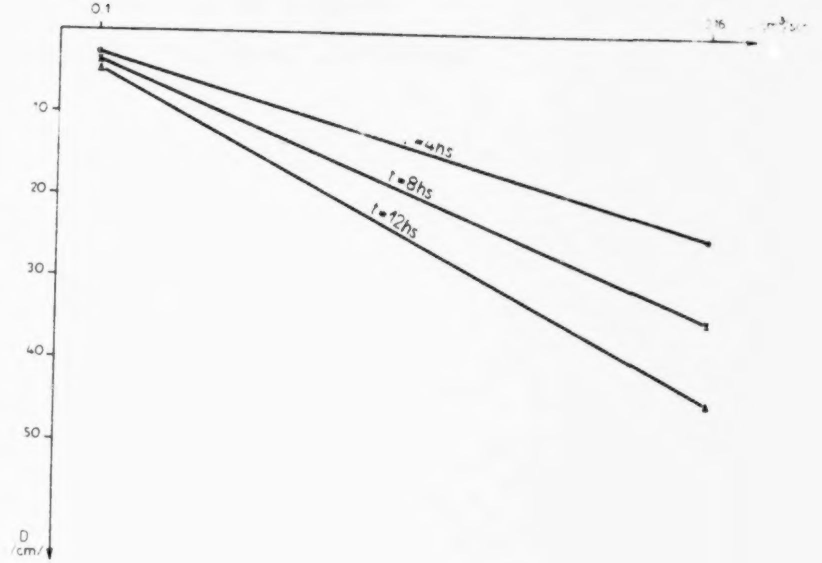


Fig. 91 Diagram of relation between depth of polluted front and dose of pollutant

○ ○ for V = 0.0017cm/sec
▲ ▲ for k = 34.5 m/d
$\Delta\gamma = 0.027 G/cm^3$

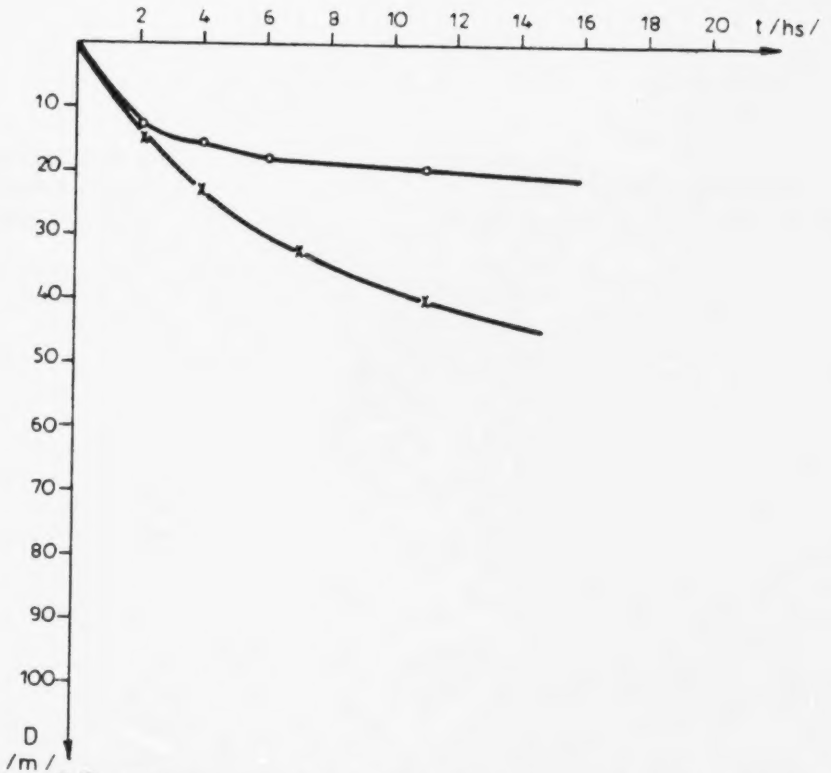


Fig. 92 Diagram of relation between the depth of polluted front position and time

o o for k_1 = 7.25 m/d
x x for k_2 = 34.5 m/d
V_1 = 0.0017 cm
Q_1 = 0.16 cm/s

The second series of tests on the soil model was carried out at a later phase of project. Their object was the demonstration of the polluted ground water flow migration as acquired in from tests performed on a slit type Helle-Shaw analogous model - in the light of results obtained from the field and laboratory tests. For, in the framework of the laboratory and field tests was found, that in practice a maximum increase in specific gravity of water polluted by the waste disposal in relation to pure water does not exceed the $\Delta \gamma = 0{,}005$ mg/l. Expected also was an elucidation of whether the observed on the Hele-Shaw model (see section 8) distribution of the polluted water just in the roof part of aquifer is not caused by the kind of applied liquid and by the specificity of the used analogy. This series of tests was made on an apparatus of a similar construction as in case of the first series, with the provision that the dimensions of the apparatus were 200 cm x 90 cm x 3,5 cm. Glass made walls of the apparatus enabled a visual observation of the process, because as mentioned at the beginning mattered only the demonstration of some tendencies.

The arrangement was filled with sand of a granulation ⌀ 1,2 to 1,4 mm. In the top portion of the sand layer installed was a basket made of copper gauze and filled with sand of granulation $d_{20} = 0{,}15$ mm, which simulated the disposal with a correspondingly reduced permeability in relation to the aquifer. Used in the tests was pure water from the waterworks with temperature + 15°C.

In order to model the water polluted with leachates leached from the disposal: water solution of permanganate of potash, normal school ink and a solution of table salt NaCl was used.

Speaking for this were the following considerations:

- each of the employed components could be brought into the model in a form of a liquid with viscosity close to water, and could be easy mixed with it,
- permanganate of potash was used, as a dry addition to sand simu-

lating the disposal as a component washable in the water environment,

- bulk density of the polluted water could be varied at will, in applying salt in optional concentration,
- dyes allowed a visual observation.

The following polluting substances were used:

1 - permanganate of potash with the bulk density equal to the bulk density of pure water,

2 - dry permanganate of potash mixed with sand simulating the disposal,

3 - solution of school ink with the bulk density increased in relation to pure water by 10 $^{o}/oo$ ($\Delta\gamma = 0{,}01$),

4 - solution of table salt by $\Delta\gamma = 0{,}026$,

5 - solution of table salt by $\Delta\gamma = 0{,}15$.

The tests were made for two schemes:

A. The polluting disposal situated above the level of the ground water table,

B. The polluting disposal situated below the level of a ground water table.

The tests were carried out in following combinations:

Scheme A - polluting solution 1 and 3, hydraulic gradients
$I_1 = 0{,}11$; $I_2 = 0{,}01$; $q = 0{,}02\ cm^3/sec.$

Scheme B - polluting solution 2,3,4,5 hydraulic gradients respectively $I_2 = 0{,}085$; $I_3 = 0{,}0085$; $I_4 = 0{,}01$; $I_5 = 0{,}008$.

Owing to the qualitative character of the demonstration tests, the

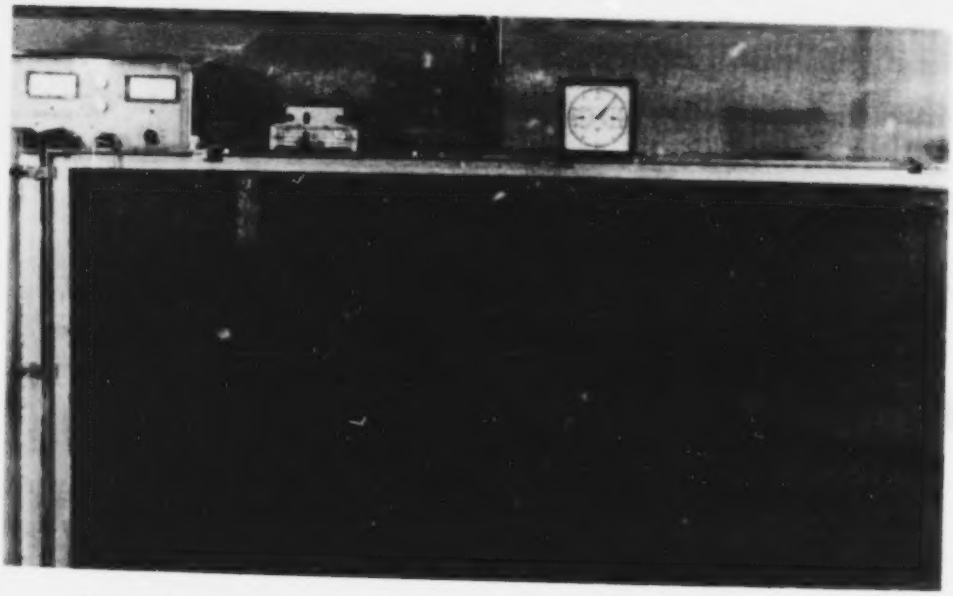


Fig. 93. Demonstration of pollutants migration from the disposal situated above ground water table.

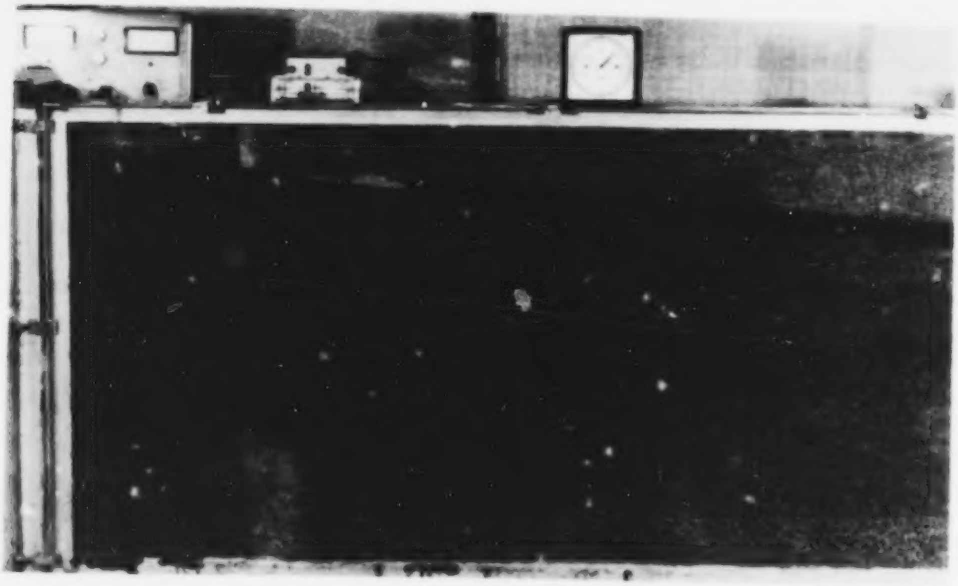


Fig. 94. Demonstration of pollutants migration from the disposal situated below ground water table (permeability of disposal 5 times smaller than aquifer one).

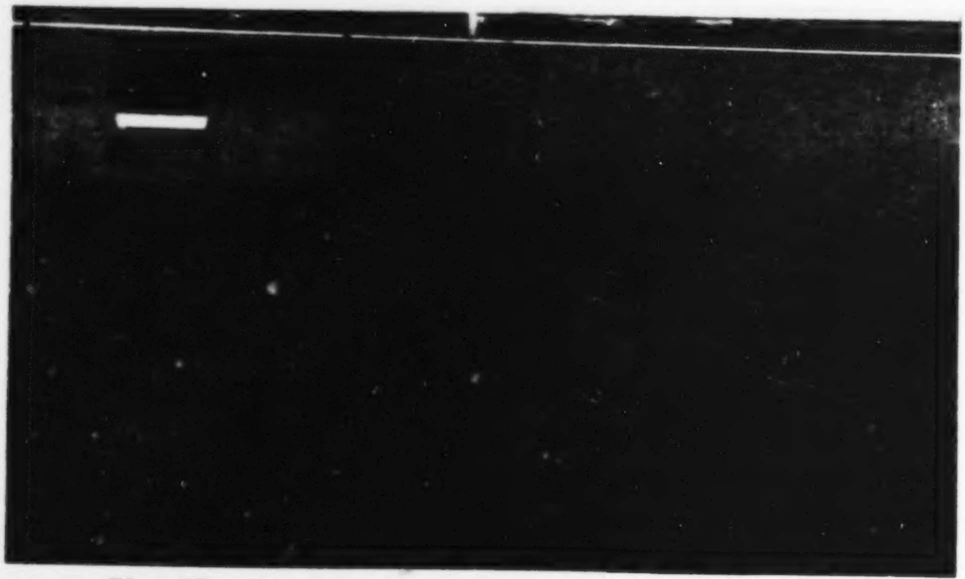


Fig. 95. Demonstration of pollutants migration from the disposal situated below ground water table (permeability of disposal 5 times smaller than aquifer one).

Fig. 96. Demonstration of pollutants migration from the disposal situated below ground water table (permeability of disposal 5 times smaller than aquifer one).

acquired results are presented, only in the form of photographs.

The results of tests allow to make the following statements:

1. With the difference of the specific gravity of polluted water and of pure water to be within limits of $\Delta \gamma$ max = 0,02 G/cm^3 and by velocities of ground water flow within V = 1 to 14 m/24 hrs the tendencies show migration in the zone of aquifer adjoining the ground water table (on the model this was about 3-4 cm wide, with the thickness of the water - logged layer of about 40 cm).
2. Portion of polluted water delivered to the surface of the ground water table migrates in the effect of a capillary rise in the zone of aeration.
3. Tendencies described in pts 1 and 2 are more distinct when smaller is hydraulic head and the velocity of filtration.
4. These tendencies are more distinct when smaller doses, of pollutants per unit of surface, are delivered and therefore for cases, with which we will have to deal with in our practice.

DEMONSTRATION TESTS PERFORMED ON A SLIT MODEL OF HELE-SHAW TYPE

The demonstrated object for this type of model was to present the selected hydraulic relationships of propagation of pollutants leached from a large waste disposal with the conditions of ground water flow and especially:

- influence of aquifer floor deformations on the depth of the polluted waters´ penetration in the flow of ground waters,
- influence of smaller disposals permeability in the relation to aquifer permeability on the vertical shape of polluted zone.

The demonstration tests were carried out with the assumption, that the specific gravity of polluted liquid qill not be greater in relation to pure water than $\Delta \gamma = 0{,}02\ G/cm^3$ (2 %) and without taking into consideration the dispersion phenomena.

Used for the tests was a slit-type apparatus, flat, of the oil type, with dimensions 0,7 x 2,0 m.

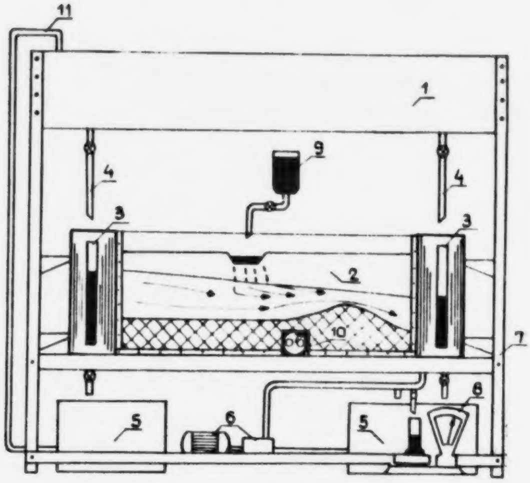
The construction of the model is shown on the enclosed drawing (fig. no. 97). It utilizes the possibility of creation a potential laminar movement of viscous liquid in a narrow space between two parallel panels. Preserved on this model is full fidelity of representation of layers in cross-section. In the scale of representation are: the permeability of the medium, the kinematic viscosity, the rate of flow and the time. In this model preserved is the field of gravitation, which is particularly important for flows of two liquids with different density in conditions of a free water table.

Model with the dimensions 1920 x 600 mm was made of aluminium plate, 6 mm thick, leaving a gap 5 mm wide.

In order to simulate the pit (in which stored was the waste material characterized with a smaller coefficient of filtration, a rectangle 300 mm long, was cut out in the plate at distance 300 mm from the front end of the modelling plate. In this rectangle in the course of performed tests plates were being placed, dependent on given variant, 8 mm thick giving a gap 3 mm wide, that represented the disposal with a 5 times smaller coefficient of permeability.

According to the program modelled was also the configuration of the aquifer bottom over which the polluted flow progressed. This was accomplished through placement and removal from the gap of apparatus a corresponding quantity of aluminium plates 150 mm high and 50 mm wide, dependent on the amount of required lowering or elevating the floor of the permeable layer.

Increase in the specific gravity of pollutants was represented in in loading the coloured oil with molybdenum.



1. Upper oil tank
2 Model in plastics channel
3 Tanks controling fluid head on the boundaries of model
4 Side tank oil inflow
5 Lower oil tanks
6 Oil pump
7 Model frame
8 Scales
9 Colored oil
10 Timer
11 Returne oil pipline

Fig.97 Scheme of viscous fluid model of Helle-Show type

In computation of model values calculated to natural sizes the following analogous scales were used:

a) scale of length and of height

$$S_L = \frac{L}{l} = \frac{\text{horizontal dimension in nature}}{\text{horizontal dimension in model}}$$

b) scale of width

$$S_A = \frac{An}{Am} = \frac{\text{natural width}}{\text{width of the model gap}}$$

Modelling the width of a natural stream 1,0 m, scale $S_A = \frac{1}{2a}$

where a = half width of the gap.

c) scale of permeability

$$S_K = \frac{k}{m} = \frac{\text{coefficient of permeability of natural soil}}{\text{coefficient of permeability in the model}}$$

$$m = \frac{ga^2}{3\nu}$$

where: g - gravity
a - half width of the gap
ν - kinematic viscosity

$$S_K = \frac{k \cdot 3\nu}{g \cdot a^2}$$

d) scale of yield

$$S_Q = \frac{Q}{q} = \frac{\text{yield in nature}}{\text{yield in model}}$$

$$S_Q = \frac{K \cdot S_A \cdot S_L}{2a \cdot m} = \frac{3 \nu \cdot K \cdot S_A \cdot S_L}{2\ ga^3}$$

I Scheme: The folloving schemes were selected for demonstrations of polluted liquid delivered non - point to the surface of the free ground water table (disposal situated above the ground water table):

a) coefficient of permeability $K = K_H = K_V = \text{const.}$;

b) flat aquifer floor

c) thickness of the ground water stream "h" was determined with the ratio to the length of the segment fed with polluted liquid "B"
$h : B = 0.1 - 2$ by $h\ \min = 10$ m,

d) quantity of polluted waters $q \leqslant 5 \cdot 10^{-3}\ Q_H$, (for conditions of moderate climate)

where:

Q_H - yield of flow of ground waters

q - yield of polluted waters

c) variable gradient of ground water table $i \leqslant 0.1$.

Scheme II: Polluted water introduced into the interior of the aquifer, (disposal placed below the ground waters table):

a) filtration space is homogeneous. Coefficient of permeability
$K = K_V = K_H = \text{const.}$ with the exception of the disposal where:
$K < Kf$.
Following relation is adopted initially:

$$K_1 = (0.01 \text{ to } 0.2) \cdot Kf$$

b) the depth of the partly immersed disposal determined with the ratio to the thickness of the ground water stream:

$$a : h = 0.1 \text{ to } 0.8;$$

c) preserved was the ratio $h : B$ within limits of 0.1 - 2;

g) ground water table gradient $i \leqslant 0.1$.

Scheme III: Demonstration of the influence of variable configuration of the aquifer floor on the shape of polluted zone:

a) homogeneous space: $k_H = K_V = K$

b) floor of a layer with variable configuration.
Variability of parameters is adopted according to designations, within limits:

$$h_1 : h = (0.2 - 1.0)$$
$$l_1 : l_2 = (0 - 5)$$
$$l_2 : h_1 = (1 - 5)$$
$$l_1 : h = (2 - 5)$$

c) thickness of the tream of ground water "h" was determined with the ratio: $h : B = 0.1 - 2$.

Scheme IV: Demonstration of influence of differences in the polluted and the pure waters´ specific gravities on the shape of the polluted zone.

For the scheme I the following conditions were modelled:

1) a) $K_H = K_V = K = 20$ m/24 hrs
   b) horizontal floor of the aquifer
   c) $h : B = 23{,}8 : 21{,}0 = 1.13$
   d) $q = 0.0149$ m^3/d

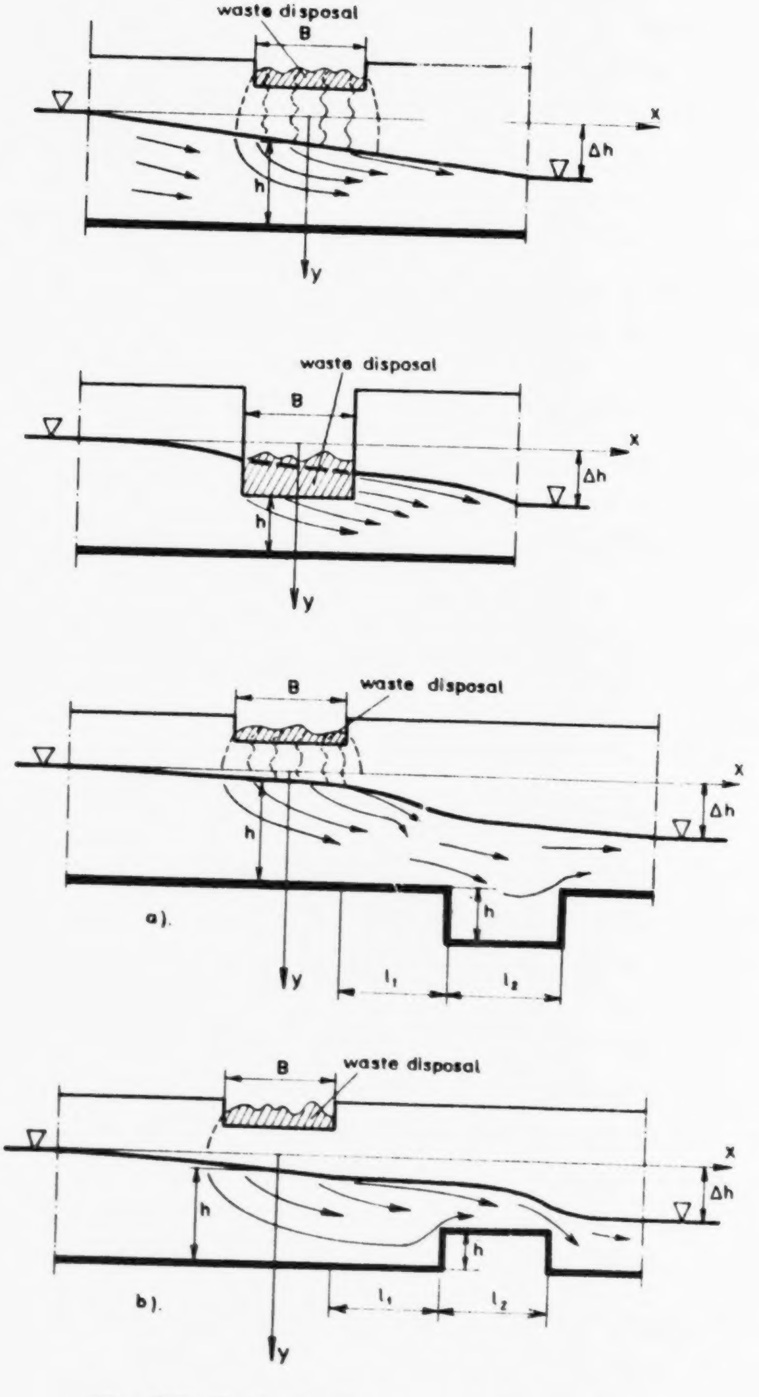


Fig. 98 Tested schemes of disposal

e) $i = 0.025$
g) length of the modelled stream $L = 92.4$ m
h) modelled time $T = 145$ days (24 hrs - day).
Obtained thickness of the polluted stream was $m = 0.28$ m.

2) a) $K_H = K_V = K = 20$ m/24 hrs
b) horizontal floor of the aquifer
c) $q = 0.118\ m^3/d$
e) $i = 0.10$
f) $Q = 35\ m^3/d$ $q : Q = 0.003$
g) length of modelled stream $L = 92.4$ m
h) modelled time $T = 46$ days.
Obtained thickness of the polluted stream was $m = 0.14$.

As could be seen the four times increase of hydraulic gradient effected the decrease of polluted stream thickness, in spite of the dose of pollutants was in the relation to clean water quantity three times higher.

For the scheme II the following conditions were modelled

1) a) Ka = 20 m/24 hrs Kd = 4 m/24 hrs
b) horizontal floor of the aquifer
c) $h : B = 19.6 : 21.0 = 0.93$
d) $q = 0.0218\ m^3/d$
e) $i = 0.025$
f) $Q = 14.88\ m^3/d$ $q : Q = 0.0023$
g) length of the modelled stream $L = 92.4$ m
h) modelled time $T = 185$ days
i) the disposal was immersed within the aquifer to a depth 2.8 m (from downstream side).

The obtained thickness of the polluted stream of ground waters was $m = 1.05$ m.

2) a) Ka = 20 m/24 hrs Kd = 4 m/24 hrs
b) horizontal floor of aquifer

c) h : B = 21 : 21 = 1.0
d) q = 0.0699 m^3/24 hrs
e) i = 0.10
f) Q = 35.0 m^3/d q : q = 0.002
g) length of modelled stream L = 92.4 m
h) modelled time T = 46 days
i) the disposal was immersed within aquifer to a depth of 2.8 m (from downstream side).

Obtained thickness of the polluted stream in ground waters was 0.7 m. It could be seen from the above that the smaller disposal permeability than the aquifer one effects a distinct decrease of the polluted stream in its neighbourhood.

For the scheme III the following conditions were modelled:

1) a) Ka = 20 m/24 hrs Kd = 4 m/24 hrs
b) floor of aquifer layer with one sinking with dimensions
h = 14.7 m;
h_1 = 10.5 m, l_1 = 30.1 m, l_2 = 10.5 m
c) h : B = 0.70
d) q = 0.116 m^3/d
e) i = 0.06
f) Q = 14 m^3/d q : Q = 0.008
g) length of modelled stream L = 92.4 m
h) modelled time T = 77 days
i) disposal immersed in the stream of ground waters.

The tests had shown that by a filtration velocity of v = 1.2 m/24 hrs, a local increase of about 70 % in the thickness of the stream of ground waters causes a decrease in this place of the flow velocity and in consequence an increase in the thickness of the polluted zone.

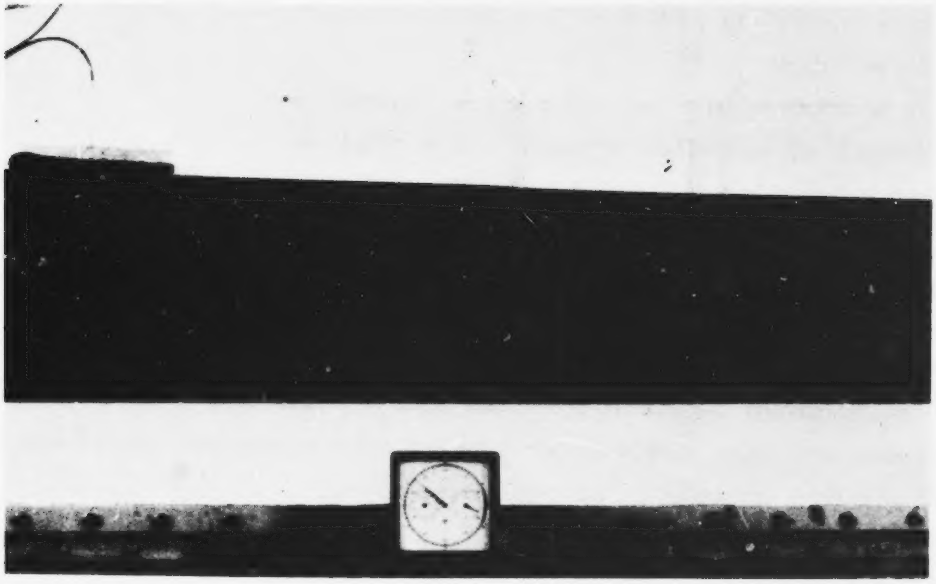


Fig. 99. Demonstration of stream of pollutants delivered on ground water table when aquifer bottom is horizontal.

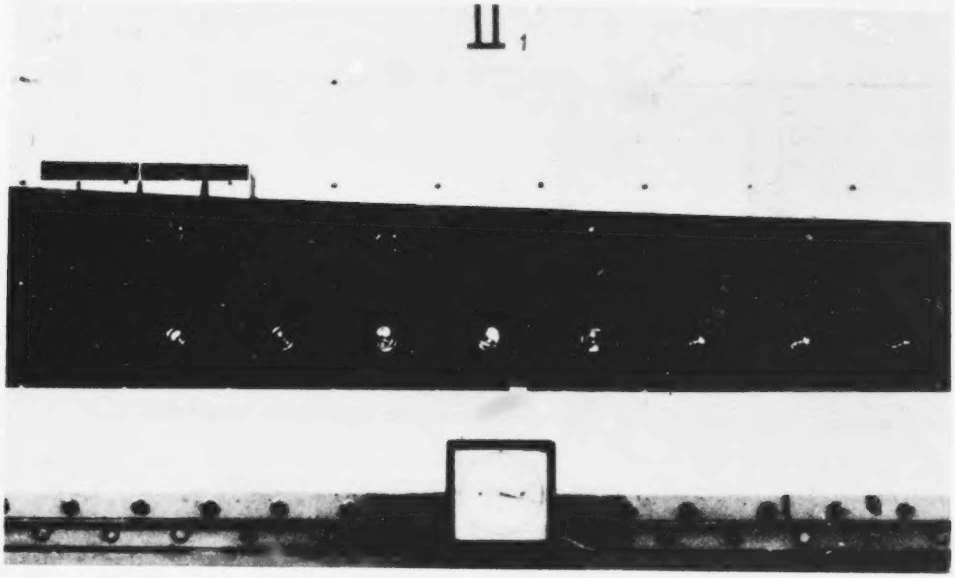


Fig. 100. Demonstration of pollutants stream filaments leaving the disposal with permeability 5 times smaller than the aquifer one.

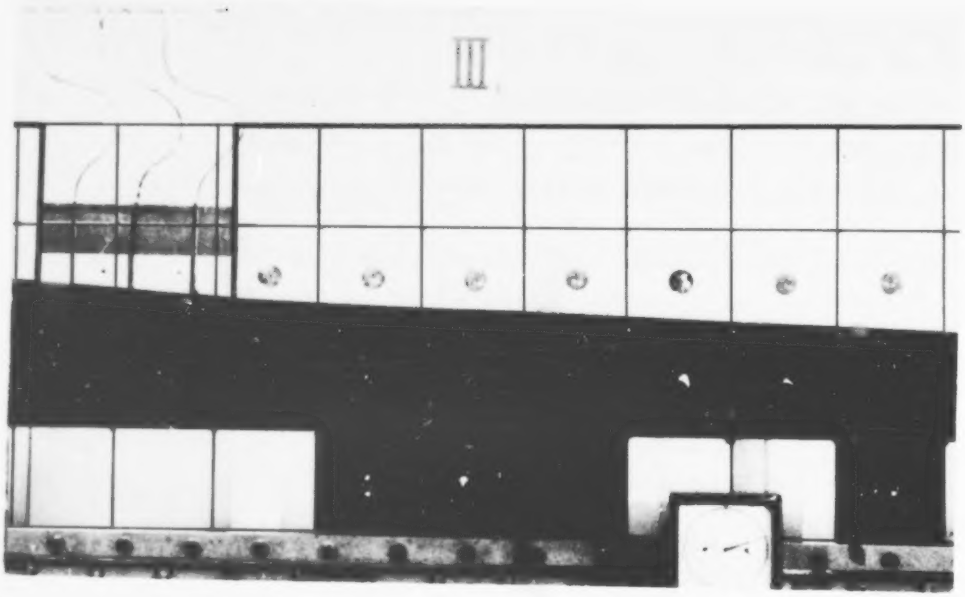


Fig. 101. Demonstration of pollutants stream filaments shape when the aquifer bottom is deformated.

2) a) Ka = 20 m/24 hrs Kd = 4 m/24 hrs

b) as above

c) h : B = 0.70

d) $q = 0.187 \ m^3/24$ hrs

e) i = 0.1

f) $Q = 21.0 \ m^3/24$ hrs

g) length of modelled stream L = 92.4 m

h) modelled time T = 46 days

i) disposal immersed in the stream of ground waters.

The test had shown, that the increase by about 80 % in a general filtration rate reduces the effect of the floor sinking on the polluted zone thickness. This finds expression in the fact, that a local (of about 70 %) increase in the thickness of aquifer causes in these conditions only a 35 % increase in the thickness of the polluted zone.

3) a) Ka = 20 m/24 hrs kd = 4 m/24 hrs

b) floor elevation

c) h : B = 0.66

d) $q_1 = 0.072 \ m^3/24$ hrs; $q_2 = 0.037 \ m^3/24$ hrs;

$q_3 = 0.080 \ m^3/24$ hrs

e) $i_1 = 0.053$ $i_2 = 0.10$ $i_3 = 0.025$

f) $Q_1 = 10.85 \ m^3/24$ hrs; $Q_2 = 35.0 \ m^3/24$ hrs;

$Q_s = 6.05 \ m^3/24$ hrs

g) length of modelled stream L = 92.4 m

h) modelled time $T_1 = 86$ days; $T_2 = 46$ days;

$T_3 = 46$ days

i) the disposal immersed in the stream of ground waters.

These tests had shown that:

In the case of existing elevation in the floor of aquifer decreasing (on a distance equal to the initial thickness of stream) the thickness of initial stream by 50 %, a local decrease in the polluted zone thickness follows to also about 50 %;

- the above phenomenon with velocity of average filtration increase by about 100 % does not produce clear changes in its course,
- by average velocity of filtration decreased by 50 %, the narrowing of the polluted zone on the elevation takes place and is estimated at about 33 %.

For the IV scheme following conditions were modelled:

1) differences in specific gravity in pure and in polluted water within the limits:

$$\Delta \gamma_1 = 0.019 \quad G/cm^3$$

$$\Delta \gamma_2 = 0.026 \quad G/cm^3$$

$$\Delta \gamma_3 = 0.110 \quad G/cm^3$$

2) hydraulic heads $I_1 = 0.01$

$I_2 = 0.025$

3) horizontal floor of aquifer.

The tests had shown that:

- for the $\Delta \gamma = 0.019\ G/cm^3$, therefore for more than two times greater, than the expected, maximum increase (in the pollution as induced by the presence of the disposal) by hydraulic gradients

$I_1 = 0.01$ and $I_2 = 0.025$ the course of the phenomenon was qualitatively identical as was in case with previously employed differences in specific gravities, $\Delta \gamma = 0.005$ G/cm^3. The zone of pollution did not show on the investigated length any tendencies to be drowned within aquifer;

- for the $\Delta \gamma_2 = 0.026$ G/cm^3 by the same conditions of flow an already clear change in this zone shape is observed, expressing itself in the increase of its thickness, the vector of gravitation appears to be an important factor in formation of the polluted zone;
- by the $\Delta \gamma_3 = 0.11$ G/cm^3 a clear qualitative change is noted in the course of the phenomenon; with velocities within the limits of laminar movement, the gravitation vector becomes an equivalent factor in shaping the polluted zone to the vector of flow; In the efect the polluted liquid sinks in the stream of pure ground waters.

TESTS PERFORMED ON ANALOGOUS EHDA MODEL

The object of the tests was a determination of the suitability of methods of the EHDA modelling for the purposes of forecasting: the directions of migration of leached out pollutants from the waste disposal to ground waters, the velocity of their migration and their relative dilution. Also to improve the system of field observations. This with the disposal no. 2 taken as an example. On this disposal, right from the start, and simultaneously with the storage were carried the field observations which gave a unique opportunity of comparing the forecast values with the real results. The model tests were carried out as two dimensional, on a plane with the help of an analogous model using an electrolytic tank. As a basis for the construction of the model, a map of transmissivity ($T = K \cdot H$) and a map of free water table was prepared. This method of modelling was adopted for the following reasons:

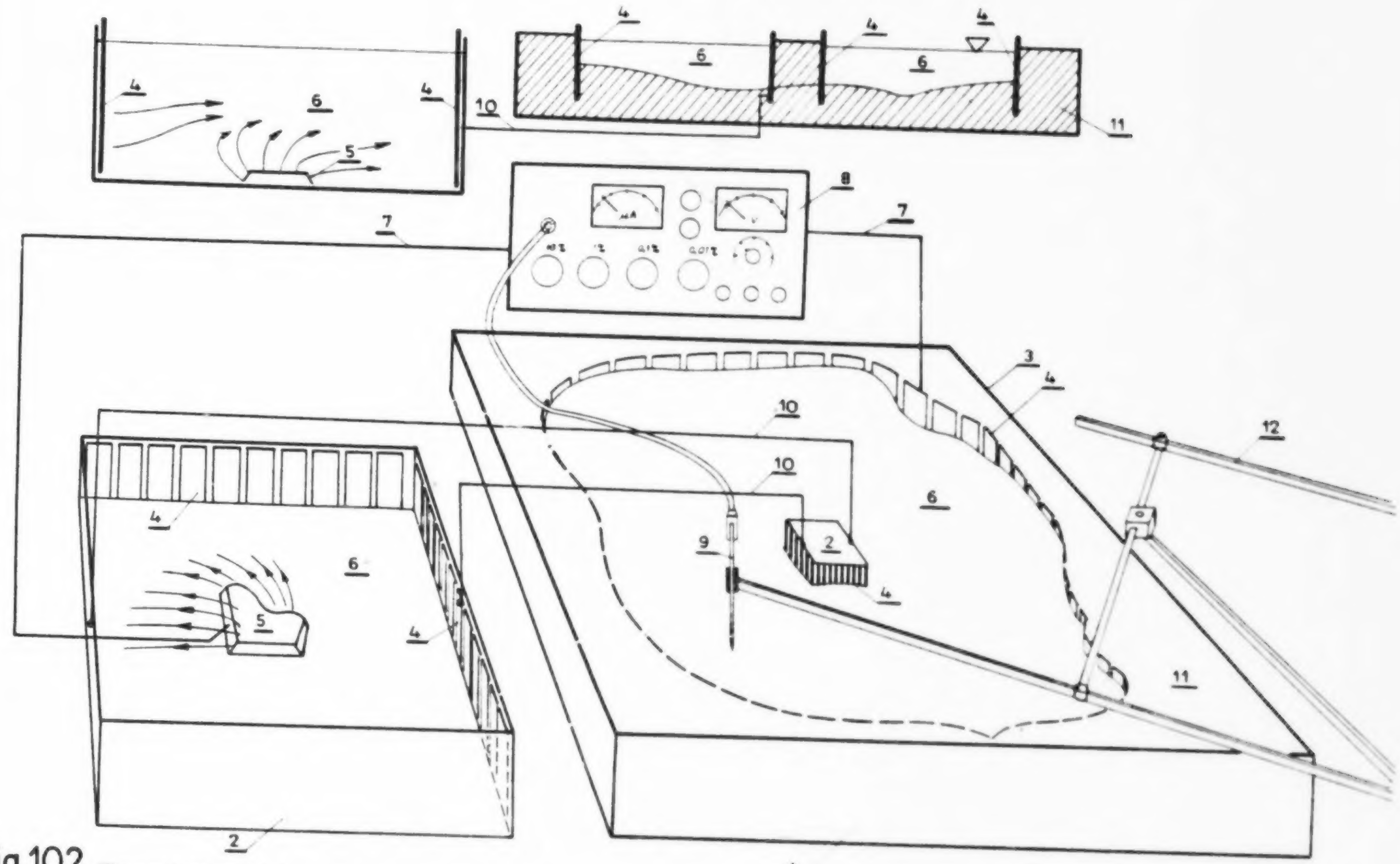


Fig.102 Electrolytic model 1— Two-dimensional electrolitic model 2— Three-dimensional model element 3— Electrolytic tank 4— Copper plates electrode - model boundary 5— Copper box electrode-open pit model 6— Low conductivity electrolyte 7— Electrode supply 8— Wheatstone bridge 9— Probe 10— Electrode juncture 11— paraffin 12— pantograph

- a relatively easy verification of the model, i.e. of conformity of representation with actual conditions of flow, especially in conditions of poor reconnaissance of hydrogeological conditions; the repeatedly made reconstruction of the model elements was necessary, which in case of a numerical modelling would require a total change of transmissivity matrix as well as its division into several submodels,

- steady character of flow in time

- inaccuracies of results achieved from models based on the electrolytic paper modelling,

- demostrativeness of the model, where was displayed a similtude both in plane and in vertical,

- the object of tests was the determination of velocity and directions of flow,

- the fact, that in some portions of the modelled region certain areas had to be demarcated where not the difference in ground water head but the shape of the floor aquifer dictated the dipping of the water table.

The model was constructed with dimensions 130 x 90 cm, which corresponded to a horizontal scale of 1 : 2000. The transmissivity of the aquifer was modelled with thickness of the electrolyte layer obtained by a corresponding configuration of the model's bottom. The of the ground water head was represented by an electric potential. In the places of monitoring wells rod electrodes were put serving to measure the potential of the field. As the bottom of the disposal is situated above the ground water table the pollutants leached out with precipitation are falling onto the stream of ground waters. In these conditions the quantity of polluted water is small and does not cause a deformation in the ground water table.

Shown on the fig. no. 42 is a hydrodynamic net with isolines of the water table and the lines of flow streams as acquired from the verified model.

This allowed to determine a probable route of the pollutants leached out from the disposal. It arises from it that the occurrence of pollutants can be expected in monitoring wells B-1, B-2, B-3, B-5, B-6, B-8, B-9 and B-10. In the remaining monitoring wells (according to model tests) should not appear any pollutions carried in streams of ground water. Using the hydrodynamic net map and the parameters of permeability (k, μ), the time of flow was calculated for each stream leaching from the waste disposal to the monitoring wells, using the formula

$$t = \sum_{i=1}^{n} \Delta t_i = \sum_{i=1}^{n} \frac{\Delta Li}{Vi} = \sum_{i=1}^{n} \frac{(\Delta Li)^2 \mu i}{\Delta H}$$

where:

t - time of flow of stream between two consecutive countours of the water table

ΔLi - distance between two consecutive contours

Vi - velocity between two consecutive contours

ΔH_i - value difference of successive contours

μi - specific yield between two successive contours.

Calculated times of flow within the reach of a potentially polluted stream are specified on the following table:

Table no.8 - 1

No.of stream	No. of monitoring well	k m/d	u	Vi m/d	ti of day	t	Remarks
0'	B-5	3.21	0.14	0.1959	587	587	1 year 122 days
0'	B-6	3.21	0.14	0.1412	1133		
		3.21	0.14	3.122	26		
		12.89	0.16	1.1837	55	1214	3 years 119 days
6	B-8	4.20	0.14	0.367	180		
		4.35	0.15	0.4288	163		
		4.35	0.14	0.8122	49	392	1 year 27 days
8	B-9	4.20	0.14	0.1450	455		
		4.35	0.14	0.1540	1364		
		4.35	0.14	0.4167	144		
		0.80	0.11	0.1647	911	2874	7 years 317 days
9	B-10	4.20	0.14	0.1450	455		
		4.35	0.14	0.1540	1364		
		4.35	0.14	0.367	218		
		0.80	0.11	0.1647	848		
		0.80	0.11	0.0482	2075	4960	13 years 212 days
10	B-1	4.20	0.14	0.242	430	430	1 year 65 days
10	B-5	4.20	0.14	0.242	430		
		3.67	0.14	0.634	208		
		3.20	0.14	0.287	428	1066	3 year 71 days
11	B-2	4.08	0.14	0.247	437	437	1 year 72 days

The calculated time values may deviate from reality, owing to:

- assumption of starting point for the migration from the verge of the disposal,
- assumption of initial point of time as the moment of pollution reaching the stream of ground waters, is not taking into account

the time required for the leaching pollutants from the disposal and the filtration through the disposal itself,

- assumption of permeability parameters from single tests points designated in conditions of great lithological variability,
- stressed by many authors differences between actual speed rate determined with tracers, and speed according to D'Arcy (and tracers can be regarded as pollutants).

Some of these factors cause an error "in plus" some "in minus" therefore all the more interesting is their comparison with reality. The second, next to the time of the pollutants appearance, of investigated accurrences on the EHDA model was their concentration in selected points. This concentration depends on the quantity of delivered polluted water to the streams of pure ground water. This quantity in turn will be a function of precipitation intensity. On the basis of experiments carried out for these region was assumed that during a summer time about 40 % precipitation will infiltrate, and in the winter time about 60 %. Specified is for each rainy period an average value of the infiltrating precipitation (P_i) into the ground waters.

Following this, on the basis of a map (fig. 42) the ground streams flowing in the direction of considered monitoring wells were demarcated. Then the width of these streams in cross-sections by the disposal and by the monitoring wells, and also their thickness were determined (on the basis of appropriate maps). Weighted average degree of pollutants dilution in ground water was computed in a following way:

Each of the demarcated streams flowing within the disposal reach conveys a flow of:

$$q_I = V_I \cdot B_I \cdot h_I \cdot \mu$$

where:

V_I - actual velocity (m/24 hrs)
B_I - width of the stream

h_I - thickness of the stream

μ - effective porosity.

This flow is enriched by a water infiltrating from the precipitation and each successive rain delivers a quantity:

$$q_i = P_i \cdot V_I \cdot B_I \cdot t$$

where additionally:

P_i - infiltration from particular rain

t - time unit (24 hrs).

Infiltrating rain water leaches from the waste disposal polluting components and brings these to the stream of ground waters. As this flow is rather very slow, the loads of pollutants delivered by particular rains superimpose themselves on one another. However during the first period a migration (through a selected point) of pollutants in waves linked is with periods of rains and dry weather.

If vertical stratification of the pure and polluted waters is not to be taken into consideration, then the averaged dilution of pollutants in ground waters on the fringe of a waste disposal should amount to:

$$\alpha = \frac{\sum q_i}{q_I + q_i}$$

while in the cross-section of the considered monitoring well this dilution in relation to the concentration in leaching waters would be:

$$\beta = \frac{a \sum q_i}{q_{II} - \sum q_i}$$

where additionally:

q_{II} - flow of water in the stream of the cross -

$a = \frac{V_{II}}{V_I}$ under consideration.

The above reasoning does not take into account the following facts:

- as the previously made tests have already indicated the pollutant most probably will flow only in the upper part of the ground waters stream, with a thickness maximum to 1.5 m, therefore their concentration will be very uneven, much greater will be near the top and much smaller in the interior of the stream; however considering a given point as a well intaking water for the consumption purposes, may beassumed that in such practice the pumped water will be mixed to become average

- the dilutions obtained from dispersion - diffusion, ionic absorption and ions exchange as well as diferent mobility of different ions - these occurrences are very important in the case of a particular considered stream, but lose their significance when the pollution assumes a character of large area, and this type of situation we shall have to deal with in cases of large waste disposals.

The dilutions computed in this way for the close to the disposal situated monitoring wells are illustrated on the following tables.

Stream "0" to the B-5 monitoring well.

Date		
Sept.13,1974	0.0013	background
Jul. 22,1975	0.075	0.0024
Sept. 10,1975	0.123	0.0169
Jul. 31,1976	0.0920	0.1890

As can be seen the increase in water pollution in the B-5 well should be visible when the pollution load delivered by infiltrating waters within the reach of disposal was to exceed in a clear way a normal state of pollution (chemical background).

The stream "0" could not reach still the B-6 well, due to a too short time (see table no. 8-1).

Stream "6" to the B-8 monitoring.

Date		
Sept. 13,1974	0.0013	background
June 23,1975	0.0578	0.000034
Oct. 20,1975	0.0954	0.000084
Jul. 31,1976	0.0692	0.00267

The streams 8 and 9 could not reach still the wells B-9 and B-10 due to insufficient time length (see table no. 8 - 1).

In these wells there should still be no pollutants.

Stream "10" to the B-1 monitoring well.

Date		
Apr.13,1975	0.0058	background
Jul. 22,1975	0.0517	for the whole time length i.e. during 147 days the pollutants displaced themselves on the distance of 35 m (1 = 0.242.147 days) and did not reach the B-1 well
Sept. 10,1975	0.1485	
Jul. 31,1976	0.201	0.386

The stream "10" could not reach still the B-5 well, due to a too short time (see table no. 8 - 1).

Stream "11" to the B-2 monitoring well.

Date		
Apr. 13,1975	0.0388	background
Jul. 22,1975	0.273	To the Sept. 10,1975, i.e.during 147 days the pollutants were displaced on 36 m distance (1 = 0.247 . 147 days and did not reach the B-2 well.
Sept. 10,1975	0.546	
Jul.31,1976	0.634	0.374

As from the above calculations appears, the pollutants should have occurred in monitoring wells B-1, B-2, B-5 and B-8. The state of dilution in particular wells could be very different. One would expect the greatest concentration in the well B-5 and then in wells B-2, B-1 and B-8.

Comparing the results of prognosis with the field observations and the water analyses one can say, that this prognosis finds its confirmation with reality in the qualitative respect. For the quantitative evaluation is still too early, and its execution will require a longer time period.

SUMMARY OF MODEL TESTS

I. Tests performed on the soil models enabled a visualization of the pollutants migration phenomenon in a porous medium, and the drawing of certain conclusions, and particularly it enabled us to demonstrate that:

1. Within limits of a 2 % difference in the weight by volume of polluted and of pure waters, the gravitation does not effect (below the disposal and in its close neighbourhood) a vertical sinking of polluted liquid, in conditions of laminar flow. This phenomenon is most probably a result of the interparticle forces

activity, which by small differences in weight by volume of both liquids, are balancing the increase in the vertical vector of gravitation. This effect of forces will depend on the soil granulation.

2. When the increase in weight by volume of polluted liquid exceeds slightly the 2 %, and the horizontal velocity of the ground water movement is $V_h = 0$ then:
   a) velocity of migration vertical depends on the dose of pollutant and the permeability, and decreases distinctly with the prolonged duration time of the phenomenon

   b) horizontal propagation depends mainly on the permeability as well as pollutants discharge which effect among other factors the dispersion and diffusion phenomena

   c) the width of the miscible zone is little changeable in time.

3. In conditions as in pt. 2, but with velocities different from zero, $V \neq 0$
   a) participation of vertical migration depends on the velocity of horizontal migration and on the permeability

   b) width of the zone of miscibility is directionally variable and depends on many factors

   c) the shape of the stream of polluted liquid depends on the pollutant dose.

4. When the difference in weight by volume of polluted liquid (delivered on the table of ground water) in relation to pure water does not exceed the 2 %, the most pollutants migrate in the zone directly adjacent to the ground water table and in zone of capillary rise. The tendencies could be observed by different filtration velocities of ground waters and is more distinct when the dose of pollutants is smaller.

II. The tests performed on an analogous model of the Hele-Shaw type allowed us to demonstrate the influence of some factors on the pollutants migration with taking into consideration the factors of time and increase distance.

These tests enabled a demonstration that:

1. Similarly as in the soil model, the phemenon of gravitation within the limits of 2 % of the weight by volume does not produce distinct vertical migration of pollutants near the disposal.

2. When the disposal is situated above table of ground water, the pollutants show tendencies to remain close to the surface of ground weter, when not taking into consideration the vertical dispersion.

3. In the case when disposal is situated below the ground water table the initial thickness of the polluted stream will depend on the ratio of disposal and aquifer permeability:

   - when the permeability coefficient of the disposal is smaller from the one of aquifer, a flow round of the stream lines under the disposal will occur. This will effect decreased thickness of the pollutant stream leaving the disposal in relation to the depth of the disposal immersion,

   - when the filtration coefficient of the disposal is equal to or greater from the filtration coefficient of the layer the shape of the stream lines is practically parallel. In this case the stream of pollutants will be close to disposal edge equal to the maximal immersion thickness of the immersed disposal in its further course the shape of the polluted stream is subject to the same laws as above.

4. Local sinking in the floor of aquifer layer causes a local increase in the polluted zone in the stream of ground waters

and a local elevation decreases this thickness. With increasing average velocity of filtration this phenomenon becomes less visible.

III. Investigations performed on the EHDA model permit provide:

1. An accurate (particularly with spatially complicated structure of aquifer) reconstruction of the hydrodynamic net, which enabled to find the prevailing directions of the pollutants' migration.
2. A quite accurate determination of directional filtration velocities, and with it the determination of time of the pollutants appearance in selected points or regions, which found its confirmation in field observations.
3. This method is much less adequate in the determination of the pollutants' dilution rate, as this phenomenon is a derivative of a greater number of factors than could be formulated in the framework of its applicability.

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EXPLANATION

Available in Language	Kind of Elaboration	Application	Estimate of Utility
1 - English	1 - General	1 - General knowledge	1 - Very important
2 - Polish	2 - Theoretical	2 - Scientific investigation	2 - Important
3 - French	3 - Methodological	3 - Disposal planning and designing	3 - Partialy important
4 - Russian	4 - Regional	4 - Field works	
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GLOSSARY

Aquifer - water bearing layer or basin

Disposal - place of waste storage

EHDA - electro - hydrodynamic analogy model

Gob - coal mining refuse = coal mining wastes

Hydrodynamic net - horizontal distribution of ground water heads

Hydrogeological conditions - complex of geological and ground waters conditions

Leachates - products of leaching

Leaching - physical and chemical extraction of components by means of water

Monitoring well - well drilled for temporarly checking of ground water quality

Open - pit - strip mine or surface mining excavation

Old open- pit - openpit abondonned after the end of mining operations

Pollutant - physical or chemical factor deteriorating ground water quality

Polluted stream - zone of ground water contaminated by convection of pollutants

Pollution - phenomenon of ground waters quality deterioration

Power plants wastes - ashes and slags removed form power plant by mechanical or hydraulic method

Soil model - ground model with sand as permeable medium

Storage - operation of waste placing.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-600/7-78-067

2.

3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE
Effects of the Disposal of Coal Waste and Ashes in Open Pits

5. REPORT DATE
April 1978 issuing date

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
Jacek Libicki, Central Research and Design Institute for Open-pit Mining, Poltegor

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Central Research and Design Institute for Open-pit Mining, Poltegor, 51-616 Wroclaw, Poland

10. PROGRAM ELEMENT NO.
EHE 623

11. CONTRACT/GRANT NO.
02-532-10

12. SPONSORING AGENCY NAME AND ADDRESS
Industrial Environmental Research Laboratory- Cin., OH
Office of Research and Development
U. S. Environmental Protection Agency
Cincinnati, Ohio 45268

13. TYPE OF REPORT AND PERIOD COVERED
Final

14. SPONSORING AGENCY CODE
EPA/600/12

15. SUPPLEMENTARY NOTES
Project supported by PL-480 Special Foreign Currency Program in cooperation with U. S. Environmental Protection Agency, Region III, Philadelphia Pennsylvania and OIA.

16. ABSTRACT

The objective of this study was to determine the extent of groundwater quality deterioration when coal mine solid waste (refuse) and power plant ashes were disposed of into open pits. In addition, disposal methods were developed and procedures for planning and designing disposal sites were formulated. Pilot studies were conducted at two experimental disposal sites, at which the groundwater was monitored. As backup to these tests, laboratory studies of the physical-chemical properties of the waste, and its leachate were conducted. Based upon the results of these studies, a full scale demonstration was conducted. From this work, the physical-chemical character of the waste material and its susceptibility to leaching of particular ions in a water environment were determined, as was the influence of precipitation on the migration of pollutants (TDS, Cl, SO_4, Na, K, Ca, Mg, NH_4, PO_4, CN, phenols, Cd, Sr, Cu, Mo, and B) to the aquifer. The level of pollution of groundwater in the vicinity of disposal sites and its dependence on local hydrogeological conditions, and particularly on hydraulic gradients was ascertained.

Recommendations for improved waste storage technology in order to limit the effect on groundwater to a minimum and guidelines for designing a monitoring system are presented.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Ground water Aquifers Leaching Refuse	Power Plant Ashes Solid Waste Disposal Poland Demonstration Project Coal Mine Waste Ground Water Pollution	48A 48G 43F 68C

18. DISTRIBUTION STATEMENT Release to the Public	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 298
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE A13 - A01

EPA Form 2220-1 (9-73)

☆ U.S. GOVERNMENT PRINTING OFFICE: 1978— 757-140/6849